Monetary Policy and Firm Heterogeneity: The Role of Leverage Since the Financial Crisis*

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Abstract

We show that the role of leverage in explaining firm-level responses to monetary policy changed around the 2007-09 financial crisis. Stock prices of firms with high leverage were less responsive to conventional monetary policy shocks in the pre-crisis period but have become more responsive to unconventional monetary policy since the crisis. Using expected volatility measures from firm-level options, we further document that financial markets have been aware of this change. We then interpret these findings through a parsimonious three-period model of firm financing with default risk. The model highlights two competing channels: firms with high leverage face steeper borrowing costs reflecting their financial overhang, making them less responsive to policy that works through the risk-free rate; but, when policy compresses credit spread in bond markets, high-leverage firms benefit disproportionately. Before the crisis, conventional monetary policy worked mainly through risk-free rates, so the first channel dominated. Since the crisis, large-scale asset purchases have compressed credit spreads, strengthening the second channel.

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1 Introduction

Since the federal funds rate hit the zero lower bound in December 2008 during the financial crisis, the Federal Reserve has relied more on unconventional policy tools, such as large-scale asset purchases (LSAP), also called quantitative easing. In this paper, we explore how the monetary transmission mechanism may have changed since the crisis, with a focus on the role of heterogeneity in firms' financing conditions. While the importance of the balance sheet of firms for the monetary transmission mechanism has long been established, recent work has highlighted the role of firm-level heterogeneity.[1] However, this literature on firm-level financial heterogeneity has typically focused on the pre-crisis period to study the transmission of conventional monetary policy actions. Our main contribution is to show that the role of financing conditions in explaining the firm-level response to monetary shocks has *reversed* in the post-crisis sample as the Fed increasingly relied on LSAP.

Our main empirical framework documents this pattern for non-financial firms in the S&P 500 index using stock price movements on FOMC announcement days. We combine firm-level characteristics (including stock prices) with measures of monetary policy shocks constructed in a narrow window around FOMC announcements from Swanson (2021). Using leverage as the measure of the firm's financial position, we find that before the financial crisis of 2007-09, stock prices of firms with higher leverage respond *less* to conventional monetary policy shocks (i.e., surprise changes to the fed funds rate) on FOMC announcement days. However, this pattern is reversed after the crisis: in the post-crisis sample, firms with higher leverage respond *more* to unconventional monetary policy shocks (i.e., surprises about large-scale asset purchases). Forward guidance shocks, which were used in both periods, do not show this dramatic reversal in transmission. Nor does the transmission of FFR shocks through leverage change when comparing the pre-crisis period to the non-ZLB portion of the post-crisis period. These results suggest that the reversal is driven by the changing composition of the Fed's policy toolkit, specifically the introduction of LSAP, rather than a structural change in how any individual shock type transmits through leverage.

The panel data allows us to control for a variety of firm-level variables, including firm fixed

[1] For an early survey of the importance of the credit channel of monetary policy, see Bernanke and Gertler (1995). For recent work on firm-level heterogeneity, see Ottonello and Winberry (2020), Jeenas (2019b), Ozdagli (2018), and Deng and Fang (2022), among others.

effects to account for permanent firm-level features and sector-time fixed effects to control for both aggregate factors and industry-specific patterns that may change over time. We also interact the monetary policy shocks with various firm characteristics to show that our results are not explained by these other variables. Our results hold across a range of robustness checks, including using alternative measures of leverage and accounting for the "information effect" in monetary shocks.

Could our results simply reflect that different firms have high leverage in the post-crisis period compared to the pre-crisis period? We show this is not the case: most firms maintained similar leverage positions across both periods, and our results hold when we exclude firms that did move significantly in the leverage distribution. Instead, our findings reflect a fundamental change in how monetary policy transmits through leverage: the same high-leverage firms that were less responsive to conventional policy pre-crisis became more responsive to unconventional policy post-crisis.

Our stock return results show opposite relationships between leverage and responsiveness for different shock types. On any given FOMC day, multiple types of surprises can occur, so a natural question is what the net effect on overall monetary policy risk looks like for high- versus low-leverage firms as the Fed's toolkit shifted. We test this using options-implied volatility measured on the day before FOMC announcements, which captures investors' expectations about how volatile a stock will be on the announcement day. We find that in the pre-crisis period, high-leverage firms have substantially lower options-implied volatility on the day before FOMC announcements, consistent with these firms being less responsive to monetary policy surprises. This negative relationship disappears in the post-crisis period, with the point estimate switching sign. The difference between the pre- and post-crisis coefficients is statistically significant, confirming a meaningful shift in how leverage relates to expected FOMC-day volatility. This is consistent with FFR shocks dominating the monetary policy landscape pre-crisis and LSAP shocks dominating post-crisis, and confirms that market participants have incorporated this changing transmission into their expectations. Importantly, this result does not rely on any particular shock decomposition or normalization, as implied volatility reflects traders' expectations across all possible shock types.

To interpret these empirical patterns, we develop a parsimonious three-period model of firm financing in which firms face default risk and are heterogeneous in their initial leverage positions. The model highlights two competing channels through which monetary policy differentially affects high-leverage firms. First, firms with more existing debt face a steeper marginal cost of borrowing that reflects their existing financial overhang. This makes them less responsive to any monetary expansion that works through lowering the risk-free rate (Ottonello and Winberry, 2020). Second, when the Federal Reserve engages in large-scale asset purchases, the pricing of default risk in bond markets is compressed, an effect that has been well documented empirically as operating through the risk premium component of credit spreads (Gilchrist and Zakrajšek, 2013). Because high-leverage firms face higher default risk, a larger share of their borrowing cost reflects this risk premium, and so they benefit disproportionately from its compression.[2]

The relative strength of these two channels depends crucially on how monetary policy affects the risk-free rate versus the risk premium components of firms' borrowing costs. Before the financial crisis, conventional monetary policy worked mainly through changes in short-term risk-free rates. In this environment, the financial overhang channel dominated: firms with high leverage were less responsive because their steeper marginal borrowing costs muted the effect of lower risk-free rates. After the crisis, the Federal Reserve's large-scale asset purchases worked substantially through compressing risk premia in long-term bond markets (Krishnamurthy and Vissing-Jorgensen, 2011; Krishnamurthy et al., 2013). Our empirical evidence shows that LSAP shocks move 10-year yields primarily through their effect on the term premium, whereas conventional FFR shocks have no discernible effect on it. In this environment, the risk premium channel can dominate the financial overhang effect, rationalizing our post-crisis finding that high-leverage firms are more responsive to monetary policy.

We provide further empirical evidence consistent with the risk premium channel. First, we show that LSAP shocks significantly compress credit spreads, measured as the difference between Moody's BAA and AAA corporate bond yields, while FFR shocks do not. This confirms that unconventional policy operates through the pricing of default risk, consistent with the findings of Gilchrist and Zakrajšek (2013), and disproportionately affects high-leverage firms. Second, we show that high-leverage firms respond to monetary policy shocks in the post-crisis sample by disproportionately increasing their debt issuance, consistent with the improved borrowing conditions that arise when risk premiums are compressed. Finally, we find that our main result of increased responsiveness since

[2] This cross-sectional prediction is consistent with recent evidence that credit spread sensitivity to monetary shocks is increasing in firm leverage and credit risk (Anderson and Cesa-Bianchi, 2020; Palazzo and Yamarthy, 2020).

the crisis is stronger for firms with a higher share of long-term debt, further supporting the role of risk premium compression in longer-term debt markets.

Related Literature Our paper is related to three strands of the literature. The first strand identifies firm-level characteristics, particularly financial constraints such as leverage, associated with a heterogeneous response to monetary policy shocks. Both Ehrmann and Fratzscher (2004) and Ottonello and Winberry (2020) find that financial constraints affect the strength of a firm's response to monetary policy. Consistent with our results, they find evidence that stock prices for firms with high leverage are relatively less responsive to monetary shocks in the pre-crisis period.[3] Ippolito et al. (2018) and Gürkaynak et al. (2022) show that the stock price of firms with more variable debt is more responsive to monetary policy shocks. While most of this literature focuses on the period prior to the financial crisis, Wu (2018) analyses stock price responsiveness during the 2008–2012 period and, consistent with our results, finds that firms with higher leverage were more responsive during this period. On the real activity side, Ottonello and Winberry (2020) and Jeenas (2019a) study how leverage affects the investment response to monetary policy at different horizons. A related line of work (Cloyne et al., 2018; Casiraghi et al., 2021) stresses the importance of firm age for monetary transmission. In our analysis, we control for the interaction of monetary policy with firm age to confirm that age is not driving the changing relationship between leverage and monetary transmission.

Second, our paper relates to a growing literature on credit spreads, risk premia, and the transmission of unconventional monetary policy. A key finding in this literature is that large-scale asset purchases compress the risk premium component of corporate credit spreads (Krishnamurthy and Vissing-Jorgensen, 2011; Gilchrist and Zakrajšek, 2013; Krishnamurthy et al., 2013). Gilchrist and Zakrajšek (2012) show more broadly that this excess bond premium component of credit spreads is an important driver of business cycle fluctuations. Two recent papers document that credit spread sensitivity to monetary shocks is heterogeneous across firms. Anderson and Cesa-Bianchi (2020)

[3]Many recent papers have explored different firm characteristics. Ozdagli (2018) finds that firms with higher information frictions are less responsive, and Lakdawala and Moreland (forthcoming) shows that firms facing higher uncertainty respond less, while Ippolito et al. (2018) and Chava and Hsu (2019) find that more financially constrained firms have a stronger response to monetary policy. Pollio (2022) investigates the relationship between information shocks and firm leverage. Other related work studies the role of the firm balance sheet in responding to ECB monetary shocks: Darmouni et al. (2020) and Holm-Hadulla and Thürwächter (2021) explore bond debt, while Auer et al. (2019) explores leverage.

use firm-level bond yields to show that credit spreads of higher leverage firms are more sensitive to monetary shocks, with the effect driven largely by the excess bond premium component. Palazzo and Yamarthy (2020) find a similar pattern in credit default swap spreads, with higher-risk firms displaying stronger sensitivity to monetary policy surprises. These papers establish the cross-sectional relationship between firm risk and monetary transmission that our model predicts. Our contribution is to show that this relationship *reversed* with the shift from conventional to unconventional policy, and to offer a theoretical framework that explains why.[4] On the real effects side, Grosse-Rueschkamp et al. (2019) study the effect of the ECB's corporate sector purchase program on firm capital structure, showing that eligible firms shifted from bank loans to bond debt. Foley-Fisher et al. (2016) find that firms more dependent on long-term debt responded more to the Federal Reserve's Maturity Extension Program. We find that this amplifying role of long-term debt holds more generally and is a pervasive feature of the post-crisis period.

Third, our paper connects to the literature on long-term corporate debt and the theoretical foundations for how monetary policy affects risk premia. Gomes et al. (2016) first explored how long-term debt matters for monetary policy, focusing on how shocks to inflation change the real burden of outstanding nominal long-term debt and thereby distort investment. Deng and Fang (2022) and Jungherr et al. (2022) show how heterogeneity in long-term debt share matters for firms' investment responses to monetary policy. On the theoretical side, He and Krishnamurthy (2013) show that financial intermediary capital constraints are a key determinant of risk premia across asset classes, while Drechsler et al. (2018) develop a model in which monetary policy affects the cost of capital through its effect on risk premia, not just through the risk-free rate. Our model features a financial overhang channel that operates in a similar spirit to the classical debt overhang of Myers (1977), whereby existing debt burdens make firms less responsive to monetary expansions. Our main contribution is to show that this channel interacts with a risk premium channel: when unconventional monetary policy compresses credit spreads (Krishnamurthy and Vissing-Jorgensen, 2011; Gilchrist and Zakrajšek, 2013), high-leverage firms benefit disproportionately because a larger share of their borrowing cost reflects default risk. This provides a new perspective on why the role of leverage in

[4]Our pre-crisis results differ somewhat from Anderson and Cesa-Bianchi (2020), likely due to differences in the sample and empirical specification (we control for the interaction of firm characteristics with the monetary policy shock).

monetary transmission changed with the shift from conventional to unconventional policy tools.

2 Data

This paper uses the daily share prices for firms in the S&P 500 index from the CRSP/Compustat Merged Security Daily dataset for July 1991 to June 2019 and firm characteristics from the 1991:Q3 to 2019:Q3 CRSP/Compustat Merged Fundamentals Quarterly dataset. We combine this firm-level data with measures of monetary policy shocks that occur on FOMC meeting days. Additionally, we merge this with a dataset of firm-level implied volatility from OptionMetrics. This section further describes these three data sources.

2.1 Monetary Policy Shocks

In the high-frequency monetary policy literature, the most common method to construct shocks involves looking at the change in futures contracts around FOMC announcements, where the underlying asset is the fed funds rate, see for example Kuttner (2001) and Bernanke and Kuttner (2005). However, in more recent years, the Federal Reserve has been using alternative, unconventional policy tools, including large scale asset purchases (quantitative easing). To account for both the conventional and unconventional monetary policy decisions, we use the shocks from the recent work of Swanson (2021). Swanson (2021) uses the methodology of Gürkaynak et al. (2005) to construct three different shocks: fed funds rate (FFR) shock, forward guidance (FG) shock, and large scale asset purchases (LSAP) shock. In our analysis, we will focus on the effect of the FFR shock in the pre-crisis vs. the LSAP shock in the post-crisis sample. For ease of interpretation, we scale the shocks so that the FFR shock has a 25bps effect on the current month's fed funds futures contract (sometimes called MP1), the FG shock has a 25bps effect on the intraday 2-year Treasury yield, and the LSAP shock has a 25bps effect on the intraday 10-year Treasury yield. Table 1 shows the summary statistics for the monetary policy shock measures for a pre-crisis sample (July 1991 to June 2008) and a post-crisis sample (August 2009 to June 2019).

2.2 Firm-Level Variables

We use the CRSP/Compustat Merged Fundamentals Quarterly sample beginning in 1991:Q3. We use the firms in the S&P 500 index and, as is common in the literature, we exclude financial firms (SIC 6000-6999). We focus on S&P 500 firms because our use of stock market data requires that news revealed in the FOMC announcements is accurately and quickly incorporated into stock prices. As discussed in Gorodnichenko and Weber (2016) there is evidence that stocks of smaller firms had no or few trades in the few hours after major macroeconomic news announcements, especially in the pre-crisis sample. On the other hand, there is evidence that stock prices of S&P 500 firms move very quickly to incorporate the information from FOMC announcements, see for example Zebedee et al. (2008). Moreover, recent work (Gürkaynak et al., 2022) shows that for S&P 500 firms, investors do take into account firm balance sheet characteristics when responding to monetary policy surprises.

Our primary measure of interest from Compustat is the firm's leverage ratio. The baseline results use the ratio of debt-to-assets measured as the sum of debt in current liabilities (Compustat item: DLCQ) and long-term debt (DLTTQ) over the book value of assets (ATQ). We also confirm our results below using an alternative measure of leverage: debt-to-capital, measured as the sum of debt in current liabilities and long-term debt over the sum of debt in current liabilities, long-term debt, and stockholder's equity (SEQQ). Table 1 displays the summary statistics for these definitions of leverage measured as the 4-quarter rolling average at the firm level.

We also use daily stock returns and implied volatility measures at the firm level. We use the daily return of a firm's share price on the day of an FOMC meeting, measured as the log difference between the closing share price on the day of the FOMC meeting and the closing share price on the day prior to the FOMC meeting. The implied volatility measures are computed using firm-level options data from OptionMetrics. The methodology used to do this calculation closely follows the one used for implied volatility of the S&P 500 index, i.e. the VIX. This daily data is available from January 1996 to June 2019. The implied volatility measures for options set to expire in greater than 3 months have the highest liquidity. But we show that our results are very similar for shorter-term options, i.e. those set to expire in less than 1 month and those set to expire between 1 month and 3 months.

Additionally, we create several control variables using these quarterly data: year-over-year real sales growth, firm size as measured by the log of the book value of assets, price-to-cost margin, receivables-minus-payables to sales, depreciation to assets, firm age, the ratio of current assets to total assets, Tobin's q, and an indicator for the firm's fiscal quarter. Using CRSP, we also include the log of market capitalization, measured for a firm on the day prior to an FOMC meeting. Including these controls is intended to capture important characteristics of the firm that could be correlated with both firm leverage and firm performance. The construction of these variables follows standard methods in the literature. We include all the details of the sample construction and summary in the online appendix.

3 Results

This section presents the main results, illustrating how leverage explains the firm-level response to monetary shocks and how that relationship has changed since the financial crisis. First, we document this changing effect using high-frequency data on stock prices. Next, we use firm-level options data to show that financial market participants have been aware of this changing responsiveness.

3.1 Evidence from Firm-level Stock Returns

We start by examining how leverage explains the stock price response to monetary policy shocks. In our baseline results, we will consider a pre-crisis sample ranging from July 1991 to June 2008 and a post-crisis sample from August 2009 to June 2019. We are thus leaving out the crisis period as categorized by July 2008 to July 2009. These dates are commonly used in the literature to identify the crisis due to turbulence in the financial markets and the presence of some asset pricing anomalies, for example, Nakamura and Steinsson (2018).

Specification Our baseline regression is estimated separately for the pre-crisis and post-crisis samples as follows:

$$s_{i,t} = \alpha_i + \alpha_{s,t} + \beta l_{i,t-1}\epsilon_t^m + \delta l_{i,t-1} + \Gamma' Z_{i,t-1} + \Upsilon \epsilon_t^m Z_{i,t-1} + e_{i,t} \tag{1}$$

where $s_{i,t}$ is the (daily) return on firm i's share price on FOMC meeting day t,[5] α_i is a firm i fixed effect, $\alpha_{s,t}$ is a sector s x FOMC meeting day t fixed effect, $l_{i,t-1}$ is firm i's average leverage (measured as debt-to-assets) for the four quarters preceding the quarter of the FOMC announcement, ϵ_t^m is the monetary policy shock, and $Z_{i,t-1}$ is a vector of firm-level controls (lagged by a quarter).

The monetary policy shock ϵ_t^m is not included separately as a regressor because it is subsumed by the sector-time fixed effect. $Z_{i,t-1}$ includes the following firm-level financial measures as controls: real sales growth, the log of the book value of assets, the price-to-cost margin, receivables-minus-payables to sales, depreciation to assets, firm age, the log of daily market capitalization, the ratio of current assets to total assets and Tobin's q. Since the firm-level characteristics are measured at the quarterly level, the leverage ratio and the firm-level controls are lagged to ensure they are predetermined at the time of the FOMC announcement. We also include a dummy for the fiscal quarter to account for differences across firms due to different positions in their fiscal year. The firm fixed effect accounts for permanent characteristics of the change in firm i's stock price that are not captured by our controls. The sector-time fixed effects are included to control for unobserved sector-level and FOMC day shocks, which may influence firm-level outcomes across all firms within the same sector. The standard errors reported in the parentheses are calculated using two-way clustering along the time and firm dimensions, but our results are also robust to using Driscoll-Kraay standard errors.

We use the high-frequency shocks from Swanson (2021) as our baseline monetary shocks. The FFR shock captures surprise changes in the federal funds rate, the LSAP shock captures surprise changes to large scale asset purchases and the FG shock captures surprise changes to forward guidance. We do not use the LSAP shock in the pre-crisis sample, since there were no large scale asset purchases in that sample; however, we do include the FFR shock and FG shock in both the pre- and post-crisis samples. Below, we show that the forward guidance shocks do not induce the changing relationship with leverage that we find with FFR and LSAP. Note also that for most of our post-crisis sample, the fed funds rate is stuck at the zero lower bound; thus, we show the post-crisis FFR shock during the non-Zero Lower Bound period only. We scale the monetary policy shock measure so that ϵ_t^m corresponds to an expansionary shock.

The coefficient β captures how the share price response to a monetary policy shock depends on

[5] $s_{i,t} = ln(p_{i,t}) - ln(p_{i,t-1})$ where the stock price p is measured at the end of the day.

leverage. We standardize leverage to be mean zero and unit variance, so these coefficients can be interpreted as the additional change in a firm's daily stock price in response to a 25bps expansionary monetary shock by moving from an average level of leverage to one standard deviation above the average leverage. In standardizing leverage, we use the full sample mean and standard deviation of leverage across all firms; we check for different standardization in the online appendix.

Results The top panel of Table 2 presents the results of estimating Equation 1 for non-financial firms in the S&P 500 in columns (1a) and (1b). The interaction coefficient of the FFR shock and leverage in the pre-crisis sample is *negative* and significant. However, in the post-crisis sample, the interaction of the LSAP shock and leverage is *positive* and significant. In particular, for firms that were one standard deviation above average leverage, their stock price rises by 0.63% *less* in response to an FFR shock in the pre-crisis sample but rises by 0.42% *more* in response to an LSAP shock in the post-crisis sample.

These results suggest that the reversal documented here is driven by the changing composition of the Fed's policy toolkit rather than a structural change in how any individual shock type transmits through leverage. Consistent with this interpretation, the relationship of the FG shock with leverage shows no significant change across periods, as shown by the p-value in Column (1d). Similarly, there is no evidence of changing transmission of the FFR shock: while the funds rate was at the ZLB for most of the post-crisis period, the difference between the pre-crisis coefficient and the non-ZLB post-crisis coefficient is not statistically significant (Column 1d).[6] Since the transmission of individual shock types through leverage has not changed across periods, our following analysis focuses on the shock type that was the primary policy instrument in each period: FFR in the pre-crisis period and LSAP in the post-crisis period.

In the bottom panels of Table 2, we estimate Equation 1 by interacting the monetary policy shock with only one firm characteristic at a time. Columns (1) - (5) show the results of the individual interaction of select firm characteristics with the monetary shock. The interaction coefficient of the FFR shock and leverage in the pre-crisis period (panel B) and the interaction coefficient of the LSAP shock and leverage in the post-crisis period (panel C) remain statistically significant and of roughly

[6]To estimate the p-values in column (1d), we estimate one regression for the full sample with appropriate indicator variables for pre-crisis, full post-crisis, and non-ZLB post-crisis periods.

the same magnitude across all the specifications. Thus, we can rule out the potential concern that our leverage results are driven by these other firm characteristics.

Robustness In Section 3.3, we provide a plethora of additional robustness checks, but before that, we provide evidence from firm-level option prices that are consistent with the idea that the role of leverage in monetary transmission has changed since the crisis.

3.2 Evidence from Firm-level Options Data

Our stock return results show that the relationship between leverage and responsiveness to monetary shocks differs across shock types: negative for FFR shocks in pre-crisis but positive for LSAP shocks in post-crisis. On any given FOMC day, multiple types of surprises can occur, so a natural question is what the net effect on overall monetary policy risk looks like for high- versus low-leverage firms, and whether that net effect changed as the Fed's toolkit shifted. We provide independent evidence on this question using options-implied volatility. The knowledge of our stock return results does not help an investor predict which *direction* the stock price of a high-leverage firm will move on the FOMC day, because the investor does not know which direction the monetary shock will go. However, an investor can use our results to predict the *relative magnitude* of the movement. Specifically, in the pre-crisis period, if FFR shocks are the dominant source of monetary policy surprises, the stock price of high-leverage firms should move less in magnitude relative to low-leverage firms. If LSAP shocks dominate post-crisis, this expectation should flip. We test this prediction using options-implied volatility measured on the day before FOMC announcements, which captures investors' expectations about how volatile the stock will be on the announcement day itself.

Specifically, we construct firm-level measures of expected volatility for non-financial S&P 500 firms using options data from the OptionMetrics dataset. The methodology used to do this calculation closely follows the one used for implied volatility of the S&P 500 index, i.e., the VIX. For each firm, we volume-weight the implied volatility of its associated options prices within three different maturity classifications. Short maturities are options expiring within 30 days; medium maturities are options expiring after 30 days but within 90 days; and long maturities are options expiring after 90 days. This gives us three measures of the implied volatility of the expected stock return.[7]

[7] The long maturity options are more liquid than the other two classifications, i.e., there are fewer missing observations

Specification Using these implied volatility measures, we explore whether the interrelation between firm-level expected volatility, leverage, and FOMC announcements has changed in a way that is consistent with our earlier results from Section 3.1. Specifically, we run the following regression

$$ivol_{i,t-1} = \alpha_i + \alpha_{s,t} + \left(1 + D_t^{post}\zeta'\right)\left[\delta l_{i,t-1} + \Gamma' Z_{i,t-1}\right] + e_{i,t} \tag{2}$$

where for an FOMC meeting occurring on day t, $ivol_{i,t-1}$ is the level of implied volatility for firm i on the day before the FOMC meeting, $l_{i,t-1}$ is average leverage (debt-to-assets) for firm i for the four quarters preceding the quarter of the FOMC announcement, D_t^{post} is a dummy that is set to 1 for the post-crisis sample of August 2009 to June 2019, ζ' is a vector of $\zeta^{(j)}$ coefficients that scale each variable j's coefficient separately, $Z_{i,t-1}$ contains a variety of firm-level controls,[8] α_i is a firm fixed effect and $\alpha_{s,t}$ is a sector-time fixed effect. Due to the data availability of options data, our sample runs from January 1996 to June 2019.

Results The estimates are presented in Table 3 with two-way clustered standard errors along the firm and time dimensions. The three columns show the results for the three different maturities. For all columns, the coefficient on leverage (δ) is negative. This means that, in the pre-crisis sample, firms with higher leverage had lower expected volatility on the day before the FOMC announcement. However, the coefficient on the interaction of leverage and the post-crisis dummy ($\zeta^{(\delta)}\delta$) is positive. Relative to the pre-crisis sample, leverage is more positively associated with implied volatility in the post-crisis sample. Moreover, the total effect in the post-crisis sample ($\delta + \zeta^{(\delta)}\delta$) is positive. This means that as measured on the day before the FOMC announcement, high-leverage firms were expected to be *less* volatile in the pre-crisis sample but *more* volatile in the post-crisis sample.

These results imply that financial market participants have updated their expectations about how leverage is related to expected volatility on FOMC announcement days. The sign flip is consistent with FFR shocks dominating the monetary policy landscape pre-crisis and LSAP shocks dominating post-crisis. When the primary source of monetary policy surprises shifts from a shock type where high leverage dampens responsiveness to one where it amplifies it, the expected volatility of high-

for the long maturities.

[8]The controls include the same as those in our baseline stock market regression, as well as the firm-level stock price on the trading day prior to the FOMC day.

leverage firms on FOMC days should shift accordingly. Importantly, this result does not depend on any particular decomposition or normalization of monetary policy shocks, as implied volatility reflects traders' expectations integrating across all possible shock types on the upcoming FOMC day.

3.3 Robustness Checks and Additional Results

In this section, we provide a variety of robustness checks to address various concerns and additional results of broader interest. Please refer to Online Appendix A.2 for the detailed discussions. Below, we provide a summary of these results.

Robustness Checks in Leverage Measures Our first set of robustness checks includes four tests regarding the leverage measures. In the first test (A.2.1), we first examine whether firms with high pre-crisis leverage also had high leverage in the post-crisis sample. We find remarkable stability in the leverage distribution across the two periods, with only modest increases in average leverage post-crisis. In the second test (A.2.2), we examine the main results while excluding firms with outlier changes in leverage from the pre-crisis to post-crisis periods, demonstrating that our main findings are not driven by firms that substantially changed their leverage positions. In the third test (A.2.3) and the fourth test (A.2.4), we show that the main results are robust to alternative standardizations of the leverage measure and to an alternative leverage measure based on debt-to-capital ratios.

Robustness Check in Sample Composition Our second robustness check shows that our stock market results are not driven by a change in the sample composition between the pre-crisis and post-crisis periods (A.2.5). We rerun our stock market specification, limiting the sample to only those firms that entered Compustat prior to 1994 and remained in the sample through at least 2017, and the results closely match our baseline results.

Robustness Checks in Monetary Policy Shocks Our third set of robustness checks addresses two tests regarding the monetary shocks. First, we examine the sensitivity of our results to excluding unscheduled FOMC meetings, which can affect financial markets differently from regularly scheduled meetings. In (A.2.6), we exclude unscheduled meetings and additionally restrict to post-1993 meetings, since the Federal Reserve did not make immediate public announcements of policy decisions before 1994. The post-crisis LSAP coefficient is unaffected, while the pre-crisis FFR coefficient remains negative but loses statistical significance, consistent with a loss of power from removing the meetings with the largest FFR variation. Second, a separate concern is that high-frequency monetary policy shocks contain substantial information effects. In the second test (A.2.7), we use the information-effect-robust shocks, following Lakdawala (2019) and Lakdawala and Schaffer (2019), to confirm that the information effects issue does not drive our baseline results.

Robustness Checks in Financial Variables We also check for different financial measures, including a first test (A.2.8) with the Fama-French excess return factors as additional controls, and a second test (A.2.9) that replaces the daily stock return with the open-to-close measure. Our baseline results hold in both cases.

4 Mechanism Illustration of Leverage and Monetary Transmission

In this section, we interpret our empirical findings through an illustration of a parsimonious three-period model in which (1) production firms are financially constrained and are heterogeneous in initial long-term (two-period) debt positions, (2) conventional monetary policy works through changing the short-term (one-period) risk-free interest rate as in Ottonello and Winberry (2020), and (3) unconventional monetary policy works through credit spread compression in long-term corporate debt prices, via large-scale asset purchases as in Gilchrist and Zakrajšek (2013). We then provide empirical support for the model's key predictions.

4.1 The Parsimonious Three-Period Model

There are three periods in the model, $t = \{0, 1, 2\}$. The gross real interest rate between period 0 and period 1 is R_1, and between period 1 and period 2 is R_2. Firms are heterogeneous in their initial leverage positions at period 0; monetary shocks arrive at the beginning of period 0; and firms make the borrowing decisions in period 0 after observing the monetary shocks.

Timeline and Decisions Each firm begins in period 0 with a fixed unity capital stock ($k_0 = 1$) and an initial debt ($b \geq 0$); therefore, leverage is b. In period 0, the firm decides on its new debt level b' and bond price q to finance its investment $q(b' - b)$. In period 1, firms produce output $f(k_1)$ with $k_1 = k_0 + q(b' - b)$, and capital is then fully depreciated. In period 2, a cash flow shock ϵ

following the distribution $\Phi(\epsilon)$ is realized in profits, leading to potential default if the shareholder cannot meet the non-negative dividend requirement. The firm then pays off creditors if it does not default. Separating gains in investment into period 1 and losses in default risk into period 2 makes the model more tractable while preserving the essential trade-off associated with financial frictions.

We now show the detailed problems for firms in reverse time order. We first show period 2. The dividend is $d_2 \equiv \epsilon - b'$. There is a cutoff capital quality shock $\bar{\epsilon} \equiv b'$ such that for any $\epsilon < \bar{\epsilon}$ the shareholder will default. This solves the expected shareholder value in period 2 as

$$\mathbf{E}v_2(b') = \int_{b'}^{\infty} \left(\epsilon - b'\right) d\Phi(\epsilon)$$

We then move backward to period 1. The shareholder states are its initial debt, b, and its new debt, b', both determined in period 0. Since capital depreciates fully from period 1 to period 2, the firm issues all profit as dividends, which is $d_1 \equiv f(k_1)$ where $k_1 = 1 + q(b' - b)$ is the capital stock in period 1. The firm value in period 1 is

$$v_1(b, b') = f(1 + q(b' - b)) + \frac{1}{R_2}\mathbf{E}v_2(b')$$

Finally, we move back to period 0. Firms choose their new debt level b', while creditors price debt based on firms' chosen debt positions b', risk-free real interest rates $\{R_1, R_2\}$, and the overall credit market conditions towards corporate risk in the long-term bonds $\{S\}$ as follows:

$$q = \frac{1}{R_1 R_2}\left[1 - S\Phi\left(b'\right)\right] \tag{3}$$

where S denotes the overall creditors' risk preferences over default risk, namely *credit spread sensitivity*. At normal times, $S = 1$, but when there is credit spread compression following unconventional monetary expansions involving large-scale asset purchases of long-term government bonds, as in Gilchrist and Zakrajšek (2013), S decreases to be below 1.

The above yields the shareholder value of the firm in period 0 as:

$$v_0(b) = \max_{b'} \left\{ \frac{f(1 + q(b' - b))}{R_1} + \frac{\int_{b'}^{\infty} \left(\epsilon - b'\right) d\Phi(\epsilon)}{R_1 R_2} \right\} \tag{4}$$

Monetary Shocks There are two types of monetary policy shocks in the model. A conventional monetary expansion (FFR shock) lowers the short-term interest rate R_1, which enters the firms' and creditors' discount factors $\frac{1}{R_1}$ in bond prices (3) and shareholder value (4). An unconventional monetary expansion involves large-scale asset purchases of long-term government bonds, compressing credit spreads by lowering S (Sack et al., 2011; Krishnamurthy and Vissing-Jorgensen, 2011). We define $m \in \{m_1 \equiv -R_1, m_2 \equiv -S\}$ as expansionary monetary policy conditions.

4.2 The Role of Leverage for Firm Value at Normal Times

Before analyzing how leverage affects firm responses to monetary shocks, we establish that the stylized three-period model preserves the key properties of existing long-term debt on firm value. To derive closed-form solutions for shareholder value, we make two assumptions: (1) ϵ follows a normal distribution, and (2) $f(\cdot) = \gamma \ln(\cdot)$ where the investment return multiplier γ is sufficiently large that all firms are endogenously financially constrained ($\gamma > R_1 k_1$ for any feasible R_1 and k_1).

We could then compound the value function (4) forward to period 2 by multiplying $v_0(b)$ with both discount factors $R_1 R_2$. This does not alter the distributional effects of monetary policy, but simplifies the derivations. We have the adjusted firm value $\widetilde{v}(b)$ as follows:

$$\widetilde{v}(b) \equiv R_1 R_2 v_0(b) = \max_{b'} \left\{ R_2 \gamma \ln\left(1 + \frac{\left[1 - S\Phi\left(b'\right)\right]\left(b' - b\right)}{R_1 R_2}\right) + \int_{b'}^{\infty} \left(\epsilon - b'\right) d\Phi(\epsilon) \right\} \tag{5}$$

Leverage and Optimal New Debt Choice b'^*. The firm's optimal debt choice b'^* trades off the marginal gain from new debt against the marginal default loss. Take the first order condition of the equation (5) with respect to b', we have $\widetilde{v}_{b'} \equiv \partial \widetilde{v}(b)/\partial b' = 0$ as follows:

$$\underbrace{\frac{\gamma}{R_1 k_1}\Big(\left[1 - S\Phi\left(b'^*\right)\right] - S\phi(b'^*)(b'^* - b)\Big)}_{\text{marginal borrowing gain}} - \underbrace{\left[1 - \Phi(b'^*)\right]}_{\text{marginal default loss}} = 0 \tag{6}$$

which could be rearranged to derive the optimal new debt issuance:

$$b'^{*} = \frac{m(b'^{*})}{S}\Big(\frac{[1 - S\Phi\,(b'^{*})]}{[1 - \Phi\,(b'^{*})]} - \frac{R_1 k_1}{\gamma}\Big) + b > b \tag{7}$$

where $k_1 = 1 + \frac{[1-S\Phi(b'^{*})]}{R_1 R_2}$ and $m(b'^{*}) \equiv [1 - \Phi\,(b'^{*})]\,/\phi(b'^{*})$ is the Mills ratio of normal distribution that governs the conditional future firm value above the default threshold, such that $m(b') > 0$, $m'(b') < 0$, and $m'(b' \to \infty) \to 0$. Equation (7) shows that the optimal new debt issuance increases when the risk-free rate R_1 or the credit risk sensitivity S decreases, moreso for the latter.

We can further show that the slope of the optimal new debt issuance policy with respect to initial leverage, $\partial b'^{*}/\partial b$, is constrained to lie between 0 and 1 and approaches 1 as initial leverage increases. Detailed derivations are in Online Appendix B.1; we only show the intuitions here. The key is that the Mills ratio, which measures conditional future firm value above the default threshold, dominates the slope. When leverage b is low, firms could borrow a substantially larger new debt $b'^{*} >> b$ because the conditional future firm value above the default threshold is high. When leverage b is sufficiently high, the Mills ratio is low, and the firm cannot issue too much new debt b'^{*}. In the limit, $b'^{*} \to b$ and $\frac{\partial b'^{*}}{\partial b} \to 1$. We could define a capital-level adjusted slope Γ of the optimal new debt issuance policy with respect to initial leverage Γ, which has two properties. First, Γ is bounded such that $0 < \Gamma \equiv R_1 k_1 \frac{\partial b'^{*}}{\partial b} < R_1 k_1 < \gamma$. Second, Γ increases when credit spread compression reduces S. Both properties are useful for our analysis of monetary policy in the next subsection.

Leverage and Firm Value Finally, applying the envelope theorem with $b' = b'^{*}$, we can show that firm value decreases in initial debt b due to the constrained borrowing gain in period 1:

$$\widetilde{v}_b \equiv \frac{\partial \widetilde{v}(b)}{\partial b} = -\frac{\gamma\,[1 - S\Phi\,(b'^{*})]}{R_1 k_1} < 0 \tag{8}$$

where $[1 - S\Phi\,(b'^{*})] > 0$ always holds since bond prices are positive.

Higher initial leverage b reduces firm value because it constrains profitable new borrowing in period 0: the marginal value of capital investment in period 1 is scaled by the bond price component $[1 - S\Phi\,(b'^{*})]$, which reflects how default risk limits the firm's ability to raise funds. Thus $\widetilde{v}_b < 0$.

4.3 The Role of Leverage for Firm Value with Monetary Shocks

In the final step, we now analyze how leverage affects monetary transmission to firm value by deriving $\widetilde{v}_{bm} \equiv \frac{\partial}{\partial m}\left(\frac{\partial \widetilde{v}(b)}{\partial b}\right)$ for $m \in \{m_1 \equiv -R_1, m_2 \equiv -S\}$. Since firms reoptimize their debt choice $b'^*(b, m)$ following monetary shocks, we separate the direct effect of initial debt b from the indirect effect through new debt issuance b'^*. Expressing $\widetilde{v}_b$ as $\widetilde{v}_b(b, b'^*(b, m), m)$, the chain rule yields:

$$\widetilde{v}_{bm} = \underbrace{\widetilde{v}_{bm}|_{\text{fix } b'^*}}_{\text{direct effect}} + \underbrace{\widetilde{v}_{bb'} \cdot \partial b'^*/\partial m}_{\text{indirect effect}} = \underbrace{\widetilde{v}_{bm}|_{\text{fix } b'^*} \cdot 1}_{\text{financial overhang}} + \underbrace{\widetilde{v}_{b'm} \cdot \partial b'^*/\partial b}_{\text{borrowing benefit}} \tag{9}$$

where $\partial b'^*/\partial m = -\widetilde{v}_{b'm}/\widetilde{v}_{b'b'}$ and $\partial b'^*/\partial b \equiv -\widetilde{v}_{bb'}/\widetilde{v}_{b'b'}$ following the implicit function theorem. The second term $\widetilde{v}_{b'm} \cdot \partial b'^*/\partial b$ can be interpreted as the product of how the marginal borrowing benefit responds to monetary shocks ($\widetilde{v}_{b'm}$) multiplied by the optimal new debt policy slope with respect to initial leverage absent monetary shocks, $\partial b'^*/\partial b = \Gamma/(R_1 k_1)$.

Conventional Monetary Shocks We first evaluate the role of leverage in firm value under expansionary conventional monetary shocks (FFR shocks), with the expansionary shock denoted by $m_1 = -R_1$ and credit spread sensitivity at normal times $S = 1$. Detailed derivations are in Online Appendix B.2. Specifically, the cross partial derivative $\widetilde{v}_{bm_1}$ can be expressed as

$$\begin{aligned}
\widetilde{v}_{bm_1} &= \frac{\partial}{\partial(-R_1)}\left(\frac{\partial \widetilde{v}(b)}{\partial b}\right)\bigg|_{\text{fix } b'^*} + \frac{\partial}{\partial(-R_1)}\left(\frac{\partial \widetilde{v}(b)}{\partial b'}\right) \cdot \frac{\partial b'^*}{\partial b} \\
&= -\frac{\gamma[1-\Phi(b'^*)]}{(R_1 k_1)^2} + \frac{[1-\Phi(b'^*)]}{R_1 k_1} \cdot \frac{1}{R_1 k_1}\Gamma \\
&= \underbrace{\frac{\gamma[1-\Phi(b'^*)]}{(R_1 k_1)^2}}_{\text{shock multiplier}} \cdot \Big(\underbrace{-1}_{\text{financial overhang}} + \underbrace{\Gamma \cdot 1/\gamma}_{\text{borrowing benefit}} \Big) < 0
\end{aligned} \tag{10}$$

where the first term is the shock multiplier, which is positive, and the second and third terms are the financial overhang channel from the initial leverage position b and the borrowing benefit channel from new debt issuance b'^*, respectively. It is evident that the borrowing benefit channel is less sensitive than unity ($\Gamma/\gamma < 1$), so it cannot overcome the financial overhang channel (-1). *Therefore, stock prices of firms with high leverage are less responsive to conventional monetary policy shocks.*

Unconventional Monetary Shocks We then evaluate the role of leverage in firm value under expansionary unconventional monetary shocks (LSAP shocks) with the expansionary shock denoted by $m_2 = -S$ and the short-term risk-free rate constrained at the zero lower bound $R_1 = 1$. Detailed derivations are in Online Appendix B.3, where we show that $\frac{\partial}{\partial(-S)}\left(\frac{\partial \widetilde{v}(b)}{\partial b'}\right) = \frac{\gamma \Phi(b'^*)}{k_1} \cdot \Psi$, where $\Psi > 1$ stands for an amplification of the marginal borrowing benefit responds to monetary shocks. We could then derive the cross partial derivative $\widetilde{v}_{bm_2}$ as

$$
\begin{aligned}
\widetilde{v}_{bm_2} &= \frac{\partial}{\partial(-S)}\left(\frac{\partial \widetilde{v}(b)}{\partial b}\right)\Bigg|_{\text{fix } b'^*} + \frac{\partial}{\partial(-S)}\left(\frac{\partial \widetilde{v}(b)}{\partial b'}\right) \cdot \frac{\partial b'^*}{\partial b} \\
&= -\frac{\gamma \Phi(b'^*)}{k_1^2} + \frac{\gamma \Phi(b'^*)}{k_1} \cdot \Psi \cdot \frac{1}{k_1}\Gamma \\
&= \underbrace{\frac{\gamma \Phi(b'^*)}{k_1^2}}_{\text{shock multiplier}} \cdot \Big(\underbrace{-1}_{\text{financial overhang}} + \underbrace{\Gamma \cdot \Psi}_{\text{borrowing benefit}} \Big) \lesseqgtr 0
\end{aligned}
\tag{11}
$$

where the first term is again the shock multiplier, which is positive, and the second and third terms are the financial overhang channel from the initial leverage position b and the borrowing benefit channel from new debt position b'^*, respectively. Again, the financial overhang channel has a sensitivity of -1. However, the borrowing benefit channel is no longer scaled by $1/\gamma < 1$ but by an amplification multiplier of the marginal borrowing benefit responds to monetary shocks $\Psi > 1$, and capital-level adjusted slope Γ of the optimal new debt issuance policy with respect to initial leverage Γ increases and approaches $R_1 k_1 > 1$ when credit spread compression lowers S.

As a result, for sufficiently large credit spread compression, the borrowing benefit channel ($\Gamma \cdot \Psi > 1$) overturns the financial overhang channel due to both the amplification of the marginal borrowing benefit responding to monetary shocks ($\Psi > 1$) and the sufficiently large optimal new debt issuance policy with respect to initial leverage ($\Gamma > 1$). *Therefore, stock prices of firms with sufficiently high leverage are more responsive to unconventional monetary policy shocks.*

Comparison and Summary The essential comparison of the role of leverage for firm value between the two monetary shocks is the relative strength of the indirect effect through borrowing benefit to the direct effect through financial overhang $\left(\frac{\widetilde{v}_{b'm}\partial b'^*/\partial b}{\widetilde{v}_{bm}|_{\text{fix } b'^*}}\right)$. Under conventional monetary expansions, the borrowing benefit channel is weaker than the financial overhang channel, as in Ottonello and Winberry (2020), so the firm value of high-leverage firms is less responsive. Under unconventional monetary expansions, the borrowing benefit channel could be stronger than the financial overhang channel for high-leverage firms due to credit spread compression, as documented in Gilchrist and Zakrajšek (2013), so the firm value of high-leverage firms could be more responsive.

4.4 Supporting Evidence for Model Mechanisms

We now provide empirical evidence linking the model's two channels to observable differences in how conventional and unconventional monetary policy affect long-term rates and credit conditions.

A central premise of the model is that conventional and unconventional monetary policy affect long-term borrowing costs through different channels. Conventional policy works through the risk-free discount factor (R_1), while unconventional policy works through the credit spread sensitivity (S). Table 4 shows the first piece of evidence for this distinction. We regress the daily change in the 10-year nominal yield and the Kim and Wright (2005) 10-year term premium estimate on the Swanson (2021) monetary policy shocks. FFR shocks in the pre-crisis period do not significantly affect either the 10-year nominal yield or the term premium. In contrast, LSAP shocks in the post-crisis period have a large and highly significant effect on both the nominal yield and the term premium, with the bulk of the effect on long rates operating through the term premium rather than through expectations about future short rates. This supports the model's distinction: conventional policy works through the risk-free rate channel, while unconventional policy works through the risk premium channel that maps to the credit spread sensitivity parameter S in our framework.

The model predicts that unconventional monetary expansions compress credit spreads and that high-leverage firms respond to this compression by increasing long-term borrowing. Table 5 tests both predictions as the second piece of evidence. Panel A examines whether monetary shocks affect credit spreads. FFR shocks do not have a significant effect on the BAA-AAA credit spread in the pre-crisis period. In contrast, the coefficient on the LSAP shocks is negative and highly significant in the post-crisis period, confirming that expansionary LSAP shocks compress credit spreads. This is consistent with the evidence in Gilchrist and Zakrajšek (2013) and with the role of the credit spread sensitivity parameter S in our model: unconventional policy compresses the risk-premium component of borrowing costs in a way that conventional rate cuts do not.

Panel B further examines whether high-leverage firms increase long-term borrowing more in response to monetary shocks. The coefficient on the LSAP × leverage interaction is positive and statistically significant in the post-crisis period, indicating that high-leverage firms increase long-term borrowing more following expansionary LSAP shocks. In contrast, the FFR × leverage interaction is not statistically significant in the pre-crisis period, suggesting that conventional monetary expansions do not differentially increase long-term borrowing for high-leverage firms.

Finally, we examine whether the stock return results are driven by long-term or short-term leverage. We decompose total firm leverage into its long-term and short-term components and re-estimate the baseline specification with both interactions included simultaneously (A.4). Consistent with the model's credit spread compression channel, which operates through the risk-premium component of long-term bond prices, the LSAP × long-term leverage interaction is positive and statistically significant in the post-crisis period, while the LSAP × short-term leverage interaction is economically small and statistically insignificant. In contrast, the FFR shock in the pre-crisis period works similarly through both components, consistent with the financial overhang channel operating through the overall leverage position rather than through a specific debt maturity. This pattern is what the model predicts: because credit spread compression affects the pricing of long-term debt ($q = \frac{1}{R_1 R_2}[1 - S\Phi(b')]$), the borrowing benefit channel should be concentrated among firms whose leverage is tilted toward long-term obligations, whereas the financial overhang channel, which operates through the risk-free discount factor R_1, should affect all leveraged firms regardless of debt maturity.

Taken together, these results trace out the model's mechanism: LSAP shocks operate through the term premium rather than through expectations about future short rates (Table 4), compress credit spreads (Table 5, Panel A), and lead high-leverage firms to increase long-term borrowing (Table 5, Panel B). This credit spread compression effect, absent under conventional policy, helps explain why the role of leverage in monetary transmission reversed with the shift to unconventional policy tools.

5 Conclusion

This paper adds to the growing empirical literature on monetary policy and firm-level heterogeneity. Using high-frequency data from the stock market, we show that the role of leverage in explaining firm-level responses to monetary policy shocks has changed since the financial crisis. Before the financial crisis, firms with higher leverage were less responsive to FFR shocks. However, in the post-crisis period, firms with higher leverage are more responsive to LSAP shocks. We show that this pattern is most consistent with a change in the composition of monetary policy shocks—specifically, the shift from conventional to unconventional policy tools—rather than a structural break in the transmission of any given shock type.

We interpret these findings through the lens of a parsimonious three-period model that highlights two competing channels: financial overhang, through which existing debt burdens make high-leverage firms less responsive to conventional risk-free rate cuts, and refinancing benefit with credit spread compression, through which LSAP shocks reduce the risk premium component of long-term borrowing costs, disproportionately benefiting high-leverage firms. Supporting the model's mechanism, we show that LSAP shocks compress credit spreads and that high-leverage firms respond by increasing long-term borrowing in the post-crisis period.

Our empirical findings and model-based interpretation highlight how the shift from conventional to unconventional monetary policy tools has altered the relationship between corporate financial structure and the monetary transmission mechanism for firms.

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Table 1: Summary Statistics

	Pre-Crisis		Post-Crisis	
	mean	std. dev.	mean	std. dev.
Stock return	0.23	3.03	0.08	1.92
Leverage (Debt-to-Assets)	0.26	0.15	0.28	0.17
Leverage (Debt-to-Capital)	0.39	0.22	0.42	0.24
LT debt share	0.79	0.23	0.87	0.16
Implied volatility, short maturity	44.36	26.42	32.25	15.30
Implied volatility, medium maturity	38.41	18.85	28.32	10.75
Implied volatility, long maturity	35.93	16.00	28.75	9.71
FFR shock	0.02	0.35	-0.05	0.05
FG shock	-0.01	0.19	0.01	0.14
LSAP shock			-0.00	0.10
Firm observations	58,673		28,967	
FOMC observations	152		80	

Notes: This table shows summary statistics for stock returns, leverage measures, long-term debt share, implied volatility, and monetary policy shocks. Stock returns and implied volatility are measured daily at the firm level. Leverage is measured quarterly at the firm level. The monetary policy shocks are measured within a 30-minute window around an FOMC announcement. The sample is non-financial firms in S&P 500 on the date of the FOMC announcement. Pre-crisis is Jul-1991 to Jun-2008, and post-crisis is Aug-2009 to June-2019.

Table 2: Response of firm-level stock returns to monetary shocks

Panel A:	(1a) Pre-Crisis	(1b) Post-Crisis	(1c) Non-ZLB Post-Crisis	(1d) Pre==Post p-value
FFR x Leverage	-0.63**		0.02	0.28
	(0.249)		(0.537)	
FG x Leverage	0.55*	0.08		0.15
	(0.307)	(0.092)		
LSAP x Leverage		0.42***		
		(0.156)		
Observations	37,961	21,907	7,234	
R^2	0.220	0.398	0.319	

Panel B:	(1) Assets	(2) Deprec./Assets	(3) Firm Age	(4) Curr. Assets	(5) Mkt. Cap.
FFR x Leverage	-0.65*	-0.67*	-0.50*	-0.56*	-0.72**
(pre-crisis)	(0.338)	(0.345)	(0.257)	(0.307)	(0.363)
Observations	37,961	37,961	37,961	37,961	37,961
R^2	0.212	0.213	0.215	0.213	0.212

Panel C:	(1) Assets	(2) Deprec./Assets	(3) Firm Age	(4) Curr. Assets	(5) Mkt. Cap.
LSAP x Leverage	0.42***	0.43***	0.42***	0.34**	0.51***
(post-crisis)	(0.147)	(0.153)	(0.152)	(0.137)	(0.160)
Observations	21,907	21,907	21,907	21,907	21,907
R^2	0.394	0.394	0.394	0.394	0.394

Notes: This table shows results from estimating $s_{i,t} = \alpha_i + \alpha_{s,t} + \beta l_{i,t-1}\epsilon_t^m + \delta l_{i,t-1} + \Gamma' Z_{i,t-1} + \Upsilon \epsilon_t^m Z_{i,t-1} + e_{i,t}$, where $s_{i,t}$ is firm-level daily stock return, α_i is a firm fixed-effect, $\alpha_{s,t}$ is an FOMC day x sector fixed-effect, $l_{i,t-1}$ is four-quarter moving average leverage normalized to have mean 0 and variance 1, ϵ_t^m are the monetary policy shocks and $Z_{i,t-1}$ is a vector of firm-level controls. In Panel A, all control variables are interacted with the monetary policy shocks. In Panels B and C, Υ is allowed to be non-zero for only the control variable listed in the column header. ϵ_t^m (FFR) is normalized to have a 25bps effect on mp1, ϵ_t^m (FG) is normalized to have a 25bps effect on the intraday 2 year yield and ϵ_t^m (LSAP) is normalized to have a 25bps effect on the intraday 10 year yield. A positive value of ϵ_t^m represents an expansionary shock. Pre-crisis is Jul-1991 to Jun-2008, post-crisis is Aug-2009 to Jun-2019 and non-ZLB is Jan-2016 to Jun-2019. The sample is non-financial firms in S&P 500 on the date of the FOMC announcement. Two-way clustered (by firm and FOMC day) standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 3: Regression of firm-level implied volatility leading up to FOMC announcement

	(1) Short Maturity	(2) Medium Maturity	(3) Long Maturity
Pre-Crisis (δ)	-2.11***	-1.80***	-1.39**
	(0.810)	(0.677)	(0.622)
Post-Crisis ($\delta + \zeta^{(\delta)}\delta$)	0.60	0.59	0.61
	(0.578)	(0.516)	(0.502)
Difference ($\zeta^{(\delta)}\delta$)	2.71***	2.40***	1.99***
	(0.834)	(0.698)	(0.644)
Observations	38,468	43,178	43,888
R^2	0.623	0.767	0.781

Notes: This table shows results from estimating $ivol_{i,t-1} = \alpha_i + \alpha_{s,t} + \left(1 + D_t^{post}\zeta'\right)[\delta l_{i,t-1} + \Gamma' Z_{i,t-1}] + e_{i,t}$, where $ivol_{i,t-1}$ is firm-level implied volatility on the day before the FOMC announcement, α_i is a firm fixed-effect, $\alpha_{s,t}$ is an FOMC day x sector fixed-effect, $l_{i,t-1}$ is four-quarter moving average leverage normalized to have mean 0 and variance 1, D_t^{post} is an indicator for the post-crisis period and $Z_{i,t-1}$ is the baseline vector of firm-level controls including the firm-level stock price at the close of prior trading day. Pre-crisis is Jan-1996 to Jun-2008 (108 obs.) and post-crisis is Aug-2009 to Jun-2019 (80 obs.).The sample is non-financial firms in S&P 500 on the date of the FOMC announcement. Two-way clustered (by firm and FOMC day) standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 4: Response of 10 year nominal yield, real yield and term premium to monetary shocks

Panel A:	10 year nominal		10 year real		10 year term premium	
	Pre-Crisis	Post-Crisis	Pre-Crisis	Post-Crisis	Pre-Crisis	Post-Crisis
ϵ_t^m (FFR)	-0.02		-0.03*		0.01	
	(0.022)		(0.017)		(0.017)	
ϵ_t^m (LSAP)		-0.42***		-0.37***		-0.35***
		(0.049)		(0.066)		(0.044)
Observations	152	69	82	69	152	69
R^2	0.011	0.389	0.055	0.302	0.011	0.395

Panel B:	10 year nominal		10 year real		10 year term premium	
	Pre-Crisis	Post-Crisis	Pre-Crisis	Post-Crisis	Pre-Crisis	Post-Crisis
ϵ_t^m (FFR)	-0.01		-0.01*		0.00	
	(0.008)		(0.006)		(0.006)	
ϵ_t^m (LSAP)		-0.08***		-0.07***		-0.06***
		(0.009)		(0.012)		(0.008)
Observations	152	69	82	69	152	69
R^2	0.011	0.389	0.055	0.302	0.011	0.395

Notes: This table shows the results from estimating $\Delta y_t = \alpha_0 + \beta\epsilon_t^m + e_{it}$, where y_t is (daily) change in the 10 year nominal rate, 10-year real rate, or the Kim & Wright 10 year term premium estimate and ϵ_t^m are the monetary policy shocks. The monetary policy shock is normalized so that a positive value represents an expansionary shock. In Panel A, ϵ_t^m (FFR) is normalized to have a 25bps effect on mp1 and ϵ_t^m (LSAP) is normalized to have a 25bps effect on the intraday 10 year yield. In Panel B, both shocks are normalized to have unit standard deviation. Pre-crisis is Jul-1991 to Jun-2008 (153 obs.) and post-crisis is Aug-2009 to Jan-2018 (69 obs.). The 10-year real rate is not available before 1999. Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 5: Response of credit spread and borrowing to monetary shocks

Panel A: BAA-AAA Credit Spread	(1a) Pre-Crisis	(1b) Post-Crisis
ϵ_t^m (FFR)	0.105	
	(0.489)	
ϵ_t^m (LSAP)		-6.657***
		(2.504)
Observations	149	80
R-squared	0.004	0.088

Panel B: Long-Term Borrowing	(2a) Pre-Crisis	(2b) Post-Crisis
ϵ_t^m (FFR) x Leverage	134.66	
	(115.604)	
ϵ_t^m (LSAP) x Leverage		1,286.13**
		(550.049)
Observations	5,281	3,781
R^2	0.137	0.167

Notes: Panel A shows results from estimating $\Delta ln(y_t) = \alpha_0 + \beta\epsilon_t^m + \epsilon_t$, where y_t is BAA-AAA spread and ϵ_t^m are the monetary policy shocks. Panel B shows results from estimating $\Delta(y_{it}) = \alpha_i + \alpha_{s,t} + \sum_{n\in N}\beta_{1n}l_{i,t-n-1}\epsilon_{t-n}^m + \delta l_{i,t-1} + \Gamma' Z_{i,t-1} + \Upsilon\epsilon_t^m Z_{i,t-1} + e_{it}$, where y_{it} is value of firm i's total long-term debt in quarter t, α_i is a firm i fixed effect, $\alpha_{s,t}$ is a quarter t x sector fixed effect, l_{it} is four-quarter moving average leverage normalized to have mean 0 and variance 1, ϵ_t^m is the sum of all high-frequency monetary policy shocks that occur in quarter t, $N = [0, 4]$ and Z_{it-1} is a vector of firm-level controls. ϵ_t^m (FFR) is normalized to have a 25bps effect on mp1, ϵ_t^m (FG) is normalized to have a 25bps effect on the intraday 2 year yield and ϵ_t^m (LSAP) is normalized to have a 25bps effect on the intraday 10 year yield. A positive value represents an expansionary shock. Sample is non-financial S&P 500 firms with at least 40 quarters of data in the pre-crisis and post-crisis sample for the dependent variable. Pre-crisis is 1991:Q3 to 2008:Q2 and post-crisis is 2009:Q3 to 2019:Q2. Two-way clustered standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Online Appendix for Monetary Policy and Firm Heterogeneity: The Role of Leverage Since the Financial Crisis (Not for Publication)

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A Empirical Appendix

A.1 Additional Details on Data Construction and Summary

Data Construction We construct the firm sample in three steps.

First, we create our investment variable using the following standard steps:

1. Flag the first date that a firm reports its gross capital stock, i.e., the level of the gross plant, property, and equipment (Compustat: ppegtq). This date must also have the necessary information to compute the change in the net capital stock: Compustat variable ppentq reported for quarter $t+1$ and either quarter t or $t-1$.

2. Interpolate any missing net investment values (ppentq) using the average of ppentq in quarters $t+1$ and $t-1$.

3. Create the capital stock beginning with the first reported gross capital stock from step #1. Then, update the following periods using the change in the net capital stock. If missing values of the net capital stock cannot be interpolated in step #2, then begin the process over with the next non-missing gross capital stock.

4. Create the quarterly intensive investment measure as the log change in the created capital stock series.

5. To remove the effect of outliers, we drop the top and bottom 0.5% of values.

Next, we define our control variables using the Compustat item names as follows:

- Ratio of current assets to total assets: $\frac{actq}{atq}$.
- Year-over-year real sales growth: log change in real *saleq*, relative to 4-quarter lagged real *saleq*. We use the quarterly price index from the BEA NIPA Table 1.3.4. Price Indexes for Gross Value Added by Sector (Non-Farm Business Index) to create all real variables.
- Firm size: log of real atq.
- Price-to-cost margin: $\frac{saleq-cogsq}{saleq}$.
- Receivables-minus-payables to sales: $\frac{rectq-apq}{saleq}$.
- Depreciation to assets: $\frac{dpq}{atq}$.
- Firm age: computed as the number of years since the firm first appeared in the Compustat database.
- Market capitalization: log of $cshoc$ multiplied by $prccd$.
- Fiscal quarter: $fqtr$.

Finally, the data is cleaned using the standard criteria:

- Keep only firms incorporated in the US ($FIC =$"USA").

- Drop firm-quarters with acquisitions greater than 5% of assets.
- Drop firm-quarters with assets or liabilities at or below zero or missing shareholder's equity ($SEQQ$).
- Drop firm-quarters that violate the accounting identity (Assets = Liabilities + Equity) by more than 10% of book value of assets.
- Winsorize leverage at 1% and 99% values and LT debt at 5% and 95% values.
- Drop firm-quarters with LT debt share greater than 1.

Summary Statistics Table A.1 provides the summary statistics of firm characteristics.

Table A.1: Summary Statistics of Firm Characteristics

	mean	std. dev.
Current to Total Assets Ratio	0.62	0.20
Log Year-Over-Year Real Sales Growth, %	3.74	21.45
Log of Real Total Assets	9.05	1.12
Price-to-Cost Margin	0.39	0.23
Receivables minus Payables to Sales	0.24	0.48
Depreciation to Assets	0.01	0.01
Firm Age	36.54	17.01
Log of Market Capitalization	15.98	1.32
Tobin's q	2.20	1.46
Observations	87,640	

Notes: The table shows summary statistics for the firm-level characteristics. All variables (excluding market capitalization) are measured quarterly at the firm level. Market capitalization is measured on the day prior to the FOMC meeting. The sample is non-financial firms in the S&P 500 between Jul-1991 and Jun-2019, excluding the financial crisis dates of Jul-2008 to Jul-2009.

A.2 Robustness Checks for the Main Results

A.2.1 Leverage in the Pre- and Post-crisis Samples

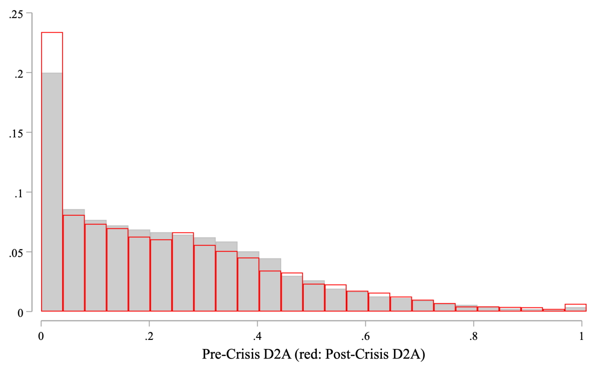
We first start by considering whether the firms that had high leverage in the pre-crisis also had high leverage in the post-crisis sample. This is potentially important because a systematic migration of less-sensitive firms toward lower leverage or more-sensitive firms toward higher leverage in the post-crisis period could, for instance, create an illusion of changed transmission mechanisms. However, we find that there is remarkable stability in the leverage distribution across the two periods, with only modest increases in average leverage post-crisis. We also demonstrate that our main findings are not driven by firms that substantially changed their leverage position. Figure A.1 below shows the distribution of leverage pre-crisis and post-crisis and how they correlate with credit ratings pre-crisis and post-crisis. We provide a discussion as follows.

First, from Table 1 in the main paper, we can see that leverage is, on average, only slightly higher in the post-crisis sample. For example, our baseline measure of leverage, debt-to-assets, has a mean of 0.42 in the post-crisis sample relative to a mean of 0.39 in the pre-crisis sample. Similarly the standard deviation of leverage is also roughly the same across the two samples. Figure A.1 shows the leverage distribution in the two samples where we have taken the firm-specific average for each sample. The grey shaded bars show the histogram for the pre-crisis sample, while the red transparent bars show the post-crisis histogram. While there is a little more mass toward the right in the post-crisis sample (and a little more toward the left in the pre-crisis sample), the distribution is quite similar in the two samples. In our baseline results presented in Section 3.1 we standardized our leverage measure by using the full sample mean and standard deviation of leverage. We have also tried using the pre-crisis mean and standard deviation to standardize our leverage measure (see Appendix Table A.3). As one would expect with the patterns from Table 1 and Figure A.1, we find these results are very similar to our baseline results.

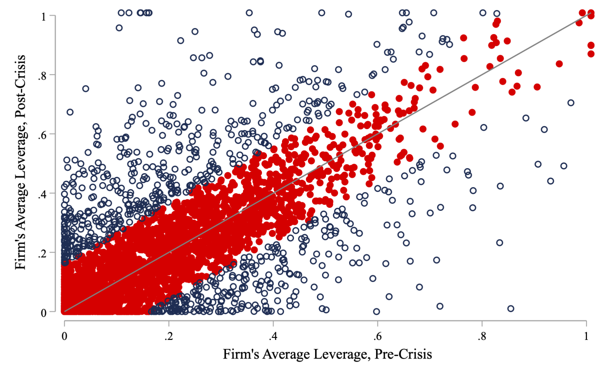
We further investigate whether firms have moved around in the leverage distribution in the two samples. Given the stability of the leverage distribution in the two samples, it is still possible that our results are driven by i) less-sensitive firms that had high leverage in the pre-crisis sample but switched to having lower leverage in the post-crisis sample and ii) more-sensitive firms with low leverage in the pre-crisis sample but switched to having higher leverage in the post-crisis sample. To this end, Figure A.1 displays a scatter plot of the firm-specific average leverage in the post-crisis sample versus the average in the pre-crisis sample. If firms' leverage across the two samples is similar, we should expect the points in the scatter plot to cluster around the 45-degree line. Figure A.1 does, in fact, show this pattern. We also investigate whether our results are driven by the firms that did change their leverage noticeably, i.e., those that are not close to the 45-degree line. In Appendix Table A.2, we present our baseline results excluding firms with more than one standard deviation away from the 45-degree line. The table confirms that our baseline stock market results are robust to excluding these outliers. This suggests that the movement of firms across the leverage distribution does not explain the difference in the transmission of monetary policy through firm leverage following the financial crisis.

Figure A.1

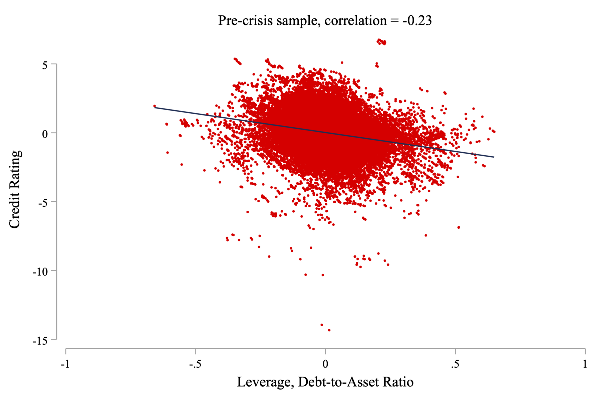
(a) Distribution of Firm Leverage



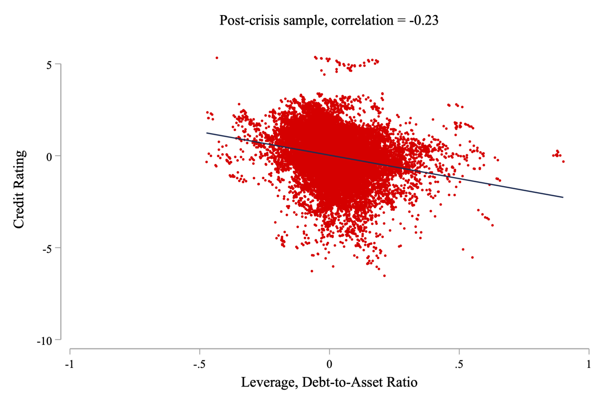
(b) Firm Leverage: Post vs. Pre



(c) Conditional Correlation of Credit Rating and Leverage: Pre-Crisis



(d) Conditional Correlation of Credit Rating and Leverage: Post-Crisis



Notes: Panel (a) plots the histogram of the quarterly firm leverage (measured as debt-to-assets), averaged across the pre-crisis (grey, shaded) and post-crisis (red, transparent) samples. Panel (b) plots the scatter plot of quarterly firm leverage (measured as debt-to-assets) averaged across the post-crisis versus the average in the pre-crisis sample. Firms below one standard deviation from the 45-degree line are shown in hollow circles. Panels (c) and (d) plot the residuals from regressing the firm's S&P long-term credit rating on our set of control variables against the residuals from regressing the firm's 4-quarter rolling leverage on a set of control variables. For all figures, pre-crisis is Jul-1991 to Jun-2008, post-crisis is Aug-2009 to Jun-2019, and the sample is non-financial firms in the S&P 500 on the date of FOMC announcement.

A.2.2 Excluding Outliers in Terms of Firm Leverage

We present our baseline results excluding firms that lie more than one standard deviation away from the 45-degree line of Figure A.1. The table confirms that our baseline stock market results are robust to excluding these outliers. This suggests that the movement of firms across the leverage distribution does not explain the difference in monetary policy transmission through firm leverage following the financial crisis. Table A.2 shows the results.

Table A.2: Robustness of baseline results to removing pre vs. post outliers

	Firm Share Price			Implied Volatility
	(1a)	(1b)		(2)
	Pre-Crisis	Post-Crisis		Long Maturity
ϵ_t^m (FFR) x Leverage	-0.50**	0.72**	Pre-Crisis (δ)	-0.85
	(0.220)	(0.346)		(0.647)
ϵ_t^m (FG) x Leverage	0.61*	0.03	Post-Crisis ($\delta + \zeta^{(\delta)}\delta$)	0.70
	(0.322)	(0.152)		(0.710)
ϵ_t^m (LSAP) x Leverage		0.42*	Difference ($\zeta^{(\delta)}\delta$)	1.56*
		(0.243)		(0.894)
Observations	31,905	17,425	Observations	35,004
R^2	0.228	0.406	R^2	0.788

Notes: Columns (1a) and (1b) are the results from estimating $s_{i,t} = \alpha_i + \alpha_{s,t} + \beta l_{i,t-1}\epsilon_t^m + \delta l_{i,t-1} + \Gamma' Z_{i,t-1} + \Upsilon \epsilon_t^m Z_{i,t-1} + e_{i,t}$, where $s_{i,t}$ is firm-level daily stock return, α_i is a firm fixed-effect, $\alpha_{s,t}$ is an FOMC day x sector fixed-effect, $l_{i,t-1}$ is four-quarter moving average leverage normalized to have mean 0 and variance 1, ϵ_t^m are the monetary policy shocks and $Z_{i,t-1}$ is a vector of firm-level controls. Column (2) is the result from estimating $ivol_{i,t-1} = \alpha_i + \alpha_{s,t} + \left(1 + D_t^{post}\zeta'\right)\left[\delta l_{i,t-1} + \Gamma' Z_{i,t-1}\right] + e_{i,t}$. ϵ_t^m (FFR) is normalized to have a 25bps effect on mp1, ϵ_t^m (FG) is normalized to have a 25bps effect on the intraday 2 year yield and ϵ_t^m (LSAP) is normalized to have a 25bps effect on the intraday 10 year yield. A positive value of ϵ_t^m represents an expansionary shock. Pre-crisis is Jul-1991 (Jan-1996 in Column (2)) to Jun-2008, and post-crisis is Aug-2009 to Jun-2019. The sample is non-financial firms in S&P 500 on the date of the FOMC announcement. We exclude 94 firms with a change in leverage from pre-crisis to post-crisis greater than one standard deviation. Two-way clustered (by firm and FOMC day) standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

A.2.3 Standardization of Firm Leverage Measure

In our baseline results, we standardized our leverage measure by using the full sample mean and standard deviation of leverage. We have also tried using the pre-crisis mean and standard deviation to standardize our leverage measure. As one would expect with the patterns from Figure A.1, we find these results shown in Table A.3 are very similar to our baseline results.

Table A.3: Robustness of baseline results with pre-crisis standardization of leverage

	Firm Share Price			Implied Volatility
	(1a)	(1b)		(2)
	Pre-Crisis	Post-Crisis		Long Maturity
ϵ_t^m (FFR) x Leverage	-0.62**	0.33	Pre-Crisis (δ)	-1.36**
	(0.244)	(0.313)		(0.610)
ϵ_t^m (FG) x Leverage	0.54*	0.08	Post-Crisis ($\delta + \zeta^{(\delta)}\delta$)	0.59
	(0.301)	(0.090)		(0.492)
ϵ_t^m (LSAP) x Leverage		0.41***	Difference ($\zeta^{(\delta)}\delta$)	1.95***
		(0.152)		(0.631)
Observations	37,961	21,907	Observations	43,888
R^2	0.220	0.398	R^2	0.781

Notes: Columns (1a) and (1b) are the results from estimating $s_{i,t} = \alpha_i + \alpha_{s,t} + \beta l_{i,t-1}\epsilon_t^m + \delta l_{i,t-1} + \Gamma' Z_{i,t-1} + \Upsilon \epsilon_t^m Z_{i,t-1} + e_{i,t}$, where $s_{i,t}$ is firm-level daily stock return, α_i is a firm fixed-effect, $\alpha_{s,t}$ is an FOMC day x sector fixed-effect, $l_{i,t-1}$ is four-quarter moving average leverage normalized (using the pre-crisis period) to have mean 0 and variance 1, ϵ_t^m are the monetary policy shocks and $Z_{i,t-1}$ is a vector of firm-level controls. Column (2) is the result from estimating $ivol_{i,t-1} = \alpha_i + \alpha_{s,t} + \left(1 + D_t^{post}\zeta'\right)[\delta l_{i,t-1} + \Gamma' Z_{i,t-1}] + e_{i,t}$. ϵ_t^m (FFR) is normalized to have a 25bps effect on mp1, ϵ_t^m (FG) is normalized to have a 25bps effect on the intraday 2 year yield and ϵ_t^m (LSAP) is normalized to have a 25bps effect on the intraday 10 year yield. A positive value of ϵ_t^m represents an expansionary shock. Pre-crisis is Jul-1991 (Jan-1996 in Column (2)) to Jun-2008, and post-crisis is Aug-2009 to Jun-2019. The sample is non-financial firms in S&P 500 on the date of the FOMC announcement. Two-way clustered (by firm and FOMC day) standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

A.2.4 Alternative Leverage Measure: Debt-to-Capital

In our baseline results, we choose our leverage measure using the debt-to-asset measure, which is widely used among many papers, including Ottonello and Winberry (2020). We have also tried using another measure that is also quite commonly used, debt-to-capital ratio; we find these results shown in Table A.4 are very similar to our baseline results.

Table A.4: Robustness of baseline results to an alternative measure of leverage: Debt-to-Capital

	Firm Share Price			Implied Volatility
	(1a)	(1b)		(2)
	Pre-Crisis	Post-Crisis		Long Maturity
ϵ_t^m (FFR) x Leverage	-0.66***	0.23	Pre-Crisis (δ)	-0.98*
	(0.222)	(0.275)		(0.542)
ϵ_t^m (FG) x Leverage	0.42	-0.05	Post-Crisis ($\delta + \zeta^{(\delta)}\delta$)	0.81*
	(0.257)	(0.085)		(0.472)
ϵ_t^m (LSAP) x Leverage		0.45***	Difference ($\zeta^{(\delta)}\delta$)	1.79***
		(0.146)		(0.590)
Observations	37,961	21,907	Observations	43,888
R^2	0.220	0.398	R^2	0.781

Notes: Columns (1a) and (1b) are the results from estimating $s_{i,t} = \alpha_i + \alpha_{s,t} + \beta l_{i,t-1}\epsilon_t^m + \delta l_{i,t-1} + \Gamma' Z_{i,t-1} + \Upsilon \epsilon_t^m Z_{i,t-1} + e_{i,t}$, where $s_{i,t}$ is firm-level daily stock return, α_i is a firm fixed-effect, $\alpha_{s,t}$ is an FOMC day x sector fixed-effect, $l_{i,t-1}$ is four-quarter moving average leverage (measured as debt-to-capital) normalized to have mean 0 and variance 1, ϵ_t^m are the monetary policy shocks and $Z_{i,t-1}$ is a vector of firm-level controls. Column (2) is the result from estimating $ivol_{i,t-1} = \alpha_i + \alpha_{s,t} + \left(1 + D_t^{post}\zeta'\right)\left[\delta l_{i,t-1} + \Gamma' Z_{i,t-1}\right] + e_{i,t}$. ϵ_t^m (FFR) is normalized to have a 25bps effect on mp1, ϵ_t^m (FG) is normalized to have a 25bps effect on the intraday 2 year yield and ϵ_t^m (LSAP) is normalized to have a 25bps effect on the intraday 10 year yield. A positive value of ϵ_t^m represents an expansionary shock. Pre-crisis is Jul-1991 (Jan-1996 in Column (2)) to Jun-2008, and post-crisis is Aug-2009 to Jun-2019. The sample is non-financial firms in S&P 500 on the date of the FOMC announcement. Two-way clustered (by firm and FOMC day) standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

A.2.5 Sample Composition Pre-Crisis and Post-Crisis

Third, we show that our stock market results are not driven by a change in the sample composition between the pre-crisis and post-crisis periods. We rerun our stock market specification, limiting the sample to only those firms that entered Compustat prior to 1993 and remained in the sample through at least 2017, and the results closely match our baseline results. Higher leverage firms are less responsive in the pre-crisis period and more responsive in the post-crisis period. This shows that our main results are not caused by certain firms entering or exiting the sample, e.g., firms that did not survive the financial crisis. Table A.5 shows the results.

Table A.5: Robustness of baseline results with consistent sample of firms

	Firm Share Price			Implied Volatility
	(1a)	(1b)		(2)
	Pre-Crisis	Post-Crisis		Long Maturity
ϵ_t^m (FFR) x Leverage	-0.43**	-1.05	Pre-Crisis (δ)	-0.34
	(0.195)	(0.644)		(0.744)
ϵ_t^m (FG) x Leverage	0.34	0.09	Post-Crisis ($\delta + \zeta^{(\delta)}\delta$)	0.77
	(0.304)	(0.248)		(0.658)
ϵ_t^m (LSAP) x Leverage		0.72**	Difference ($\zeta^{(\delta)}\delta$)	1.11*
		(0.340)		(0.668)
Observations	14,483	8,536	Observations	17,648
R^2	0.247	0.436	R^2	0.758

Notes: Columns (1a) and (1b) are the results from estimating $s_{i,t} = \alpha_i + \alpha_{s,t} + \beta l_{i,t-1}\epsilon_t^m + \delta l_{i,t-1} + \Gamma' Z_{i,t-1} + \Upsilon \epsilon_t^m Z_{i,t-1} + e_{i,t}$, where $s_{i,t}$ is firm-level daily stock return, α_i is a firm fixed-effect, $\alpha_{s,t}$ is an FOMC day x sector fixed-effect, $l_{i,t-1}$ is four-quarter moving average leverage normalized to have mean 0 and variance 1, ϵ_t^m are the monetary policy shocks and $Z_{i,t-1}$ is a vector of firm-level controls. Column (2) is the result from estimating $ivol_{i,t-1} = \alpha_i + \alpha_{s,t} + \left(1 + D_t^{post}\zeta'\right)[\delta l_{i,t-1} + \Gamma' Z_{i,t-1}] + e_{i,t}$. ϵ_t^m (FFR) is normalized to have a 25bps effect on mp1, ϵ_t^m (FG) is normalized to have a 25bps effect on the intraday 2 year yield and ϵ_t^m (LSAP) is normalized to have a 25bps effect on the intraday 10 year yield. A positive value of ϵ_t^m represents an expansionary shock. Pre-crisis is Jul-1991 (Jan-1996 in Column (2)) to Jun-2008, and post-crisis is Aug-2009 to Jun-2019. The sample is non-financial firms in S&P 500 on the date of the FOMC announcement that entered Compustat prior to 1993 and remained in the sample through at least 2017. Two-way clustered (by firm and FOMC day) standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

A.2.6 Including Only Scheduled FOMC Meetings

Unscheduled FOMC meetings can affect financial markets differently from regularly scheduled meetings, as unscheduled meetings typically occur in times of economic turmoil. The unscheduled meetings are also instances in which the Federal Reserve is more likely to release information about economic fundamentals, for example, Lakdawala and Schaffer (2019). Thus, we want to ensure our results are not driven by these unscheduled meetings. This issue only arises in the pre-crisis sample, with 16 unscheduled meetings, while our post-crisis sample has none. Additionally, the Federal Reserve did not start making immediate post-FOMC meeting public announcements of policy decisions until 1994. Excluding pre-1994 meetings and unscheduled meetings gives results that are quite similar to the baseline case. Table A.6 shows these results.

Table A.6: Robustness of baseline results with scheduled, post-1993 FOMC meetings only

	Firm Share Price			Implied Volatility
	(1a)	(1b)		(2)
	Pre-Crisis	Post-Crisis		Long Maturity
ϵ_t^m (FFR) x Leverage	-0.04	0.34	Pre-Crisis (δ)	-1.31**
	(0.166)	(0.320)		(0.621)
ϵ_t^m (FG) x Leverage	0.33	0.08	Post-Crisis ($\delta + \zeta^{(\delta)}\delta$)	0.63
	(0.210)	(0.092)		(0.494)
ϵ_t^m (LSAP) x Leverage		0.42***	Difference ($\zeta^{(\delta)}\delta$)	1.94***
		(0.156)		(0.663)
Observations	29,759	21,907	Observations	42,067
R^2	0.192	0.398	R^2	0.779

Notes: Columns (1a) and (1b) are the results from estimating $s_{i,t} = \alpha_i + \alpha_{s,t} + \beta l_{i,t-1}\epsilon_t^m + \delta l_{i,t-1} + \Gamma' Z_{i,t-1} + \Upsilon \epsilon_t^m Z_{i,t-1} + e_{i,t}$, where $s_{i,t}$ is firm-level daily stock return, α_i is a firm fixed-effect, $\alpha_{s,t}$ is an FOMC day x sector fixed-effect, $l_{i,t-1}$ is four-quarter moving average leverage normalized to have mean 0 and variance 1, ϵ_t^m are the monetary policy shocks and $Z_{i,t-1}$ is a vector of firm-level controls. Column (2) is the result from estimating $ivol_{i,t-1} = \alpha_i + \alpha_{s,t} + \left(1 + D_t^{post}\zeta'\right)\left[\delta l_{i,t-1} + \Gamma' Z_{i,t-1}\right] + e_{i,t}$. ϵ_t^m (FFR) is normalized to have a 25bps effect on mp1, ϵ_t^m (FG) is normalized to have a 25bps effect on the intraday 2 year yield and ϵ_t^m (LSAP) is normalized to have a 25bps effect on the intraday 10 year yield. A positive value of ϵ_t^m represents an expansionary shock. Pre-crisis is Jan-1994 (Jan-1996 in Column (2)) to Jun-2008, and post-crisis is Aug-2009 to Jun-2019. The sample is non-financial firms in S&P 500 on the date of the (scheduled) FOMC announcement. Two-way clustered (by firm and FOMC day) standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

A.2.7 Using Information Effect Robust Shocks in Lakdawala (2019)

There may still be a concern that even on regularly scheduled FOMC meetings, the high-frequency monetary policy shocks contain a substantial information component. To address this concern, we first use forecast data, following the approach in Lakdawala (2019), to cleanse the monetary policy shock of any information effect. Table A.7 shows the results. These results confirm that this issue does not drive our baseline results.

Table A.7: Robustness of stock return results to info-robust shocks

	(1a) Pre-Crisis	(1b) Post-Crisis
ϵ_t^m (FFR) x Leverage	-2.94***	0.12
	(1.044)	(1.014)
ϵ_t^m (FG) x Leverage	1.75*	-0.44
	(1.050)	(0.421)
ϵ_t^m (LSAP) x Leverage		2.10**
		(0.930)
Observations	37,961	18,243
R^2	0.221	0.417

This table shows results from estimating $s_{i,t} = \alpha_i + \alpha_{s,t} + \beta l_{i,t-1}\epsilon_t^m + \delta l_{i,t-1} + \Gamma' Z_{i,t-1} + \Upsilon \epsilon_t^m Z_{i,t-1} + e_{i,t}$, where $s_{i,t}$ is firm-level daily stock return, α_i is a firm fixed-effect, $\alpha_{s,t}$ is an FOMC day x sector fixed-effect, $l_{i,t-1}$ is four-quarter moving average leverage normalized to have mean 0 and variance 1, ϵ_t^m are the monetary policy shocks and $Z_{i,t-1}$ is a vector of firm-level controls. ϵ_t^m (FFR) is normalized to have a 25bps effect on mp1, ϵ_t^m (FG) is normalized to have a 25bps effect on the intraday 2 year yield and ϵ_t^m (LSAP) is normalized to have a 25bps effect on the intraday 10 year yield. A positive value of ϵ_t^m represents an expansionary shock. The monetary policy shocks are cleansed of information effects (as in Lakdawala (2019)). Pre-crisis is Jul-1991 to Jun-2008, and post-crisis is Aug-2009 to Jun-2019. The sample is non-financial firms in S&P 500 on the date of the FOMC announcement. Two-way clustered (by firm and FOMC day) standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

A.2.8 Controlling for the Fama-French Excess Returns

Our results also hold with Fama-French factors. In Table A.8 below, we show that our baseline specification while controlling for three factors: i) firm-specific beta, ii) size as captured by the firm's market capitalization on the day before the FOMC announcement, and iii)firm-level book to market.

Table A.8: Response of firm-level stock returns to monetary policy shocks: Controlling for Fama-French characteristics

	(1a) Pre-Crisis	(1b) Post-Crisis
ϵ_t^m (FFR) x Leverage	-0.41***	0.20
	(0.137)	(0.263)
ϵ_t^m (FG) x Leverage	0.25	0.27***
	(0.298)	(0.089)
ϵ_t^m (LSAP) x Leverage		0.27*
		(0.156)
Observations	36,149	21,754
R^2	0.241	0.397

This table shows results from estimating $s_{i,t} = \alpha_i + \alpha_{s,t} + \beta l_{i,t-1}\epsilon_t^m + \delta l_{i,t-1} + \Gamma' Z_{i,t-1} + \Upsilon \epsilon_t^m Z_{i,t-1} + e_{i,t}$, where $s_{i,t}$ is firm-level daily stock return, α_i is a firm fixed-effect, $\alpha_{s,t}$ is an FOMC day x sector fixed-effect, $l_{i,t-1}$ is four-quarter moving average leverage normalized to have mean 0 and variance 1, ϵ_t^m are the monetary policy shocks and $Z_{i,t-1}$ is a vector of firm-level controls (including book-to-market ratio and firm betas). ϵ_t^m (FFR) is normalized to have a 25bps effect on mp1, ϵ_t^m (FG) is normalized to have a 25bps effect on the intraday 2 year yield and ϵ_t^m (LSAP) is normalized to have a 25bps effect on the intraday 10 year yield. A positive value of ϵ_t^m represents an expansionary shock. Pre-crisis is Jul-1991 to Jun-2008, and post-crisis is Aug-2009 to Jun-2019. The sample is non-financial firms in S&P 500 on the date of the FOMC announcement. Two-way clustered (by firm and FOMC day) standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

A.2.9 Alternative Measure of Stock Returns

Our results also hold with an alternative measure of stock returns using the open-to-close price differences. We show the results in Table A.9 below.

Table A.9: Response of firm-level stock returns (open-to-close) to monetary shocks

	(1a) Pre-Crisis	(1b) Post-Crisis
ϵ_t^m (FFR) x Leverage	-0.26*	-0.01
	(0.155)	(0.334)
ϵ_t^m (FG) x Leverage	0.28	0.01
	(0.218)	(0.077)
ϵ_t^m (LSAP) x Leverage		0.45***
		(0.113)
Observations	9,288	21,907
R^2	0.426	0.425

Notes: This table shows results from estimating $s_{i,t} = \alpha_i + \alpha_{s,t} + \beta l_{i,t-1}\epsilon_t^m + \delta l_{i,t-1} + \Gamma' Z_{i,t-1} + \Upsilon \epsilon_t^m Z_{i,t-1} + e_{i,t}$, where $s_{i,t}$ is firm-level daily stock return (measured from open-to-close), α_i is a firm fixed-effect, $\alpha_{s,t}$ is an FOMC day x sector fixed-effect, $l_{i,t-1}$ is four-quarter moving average leverage normalized to have mean 0 and variance 1, ϵ_t^m are the monetary policy shocks and $Z_{i,t-1}$ is a vector of firm-level controls. ϵ_t^m (FFR) is normalized to have a 25bps effect on mp1, ϵ_t^m (FG) is normalized to have a 25bps effect on the intraday 2 year yield and ϵ_t^m (LSAP) is normalized to have a 25bps effect on the intraday 10 year yield. A positive value of ϵ_t^m represents an expansionary shock. Pre-crisis is Jul-1991 to Jun-2008, and post-crisis is Aug-2009 to Jun-2019. The sample is non-financial firms in S&P 500 on the date of the FOMC announcement. Two-way clustered (by firm and FOMC day) standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

A.3 Distinguishing Short-term and Long-term Leverage

In Table A.10, we show the results where we simultaneously include short-term and long-term leverage (and interaction with monetary policy) in our baseline specification.

Table A.10: Response of firm-level stock returns to monetary shocks: LT vs. ST leverage

	(1a) Pre-Crisis	(1b) Post-Crisis
ϵ_t^m (FFR) x ST Leverage	-0.46***	0.19
	(0.139)	(0.482)
ϵ_t^m (FFR) x LT Leverage	-0.51***	0.18
	(0.187)	(0.266)
ϵ_t^m (LSAP) x ST Leverage		0.19
		(0.193)
ϵ_t^m (LSAP) x LT Leverage		0.41**
		(0.170)
Observations	37,961	21,907
R^2	0.221	0.398

Notes: This table shows results from estimating $s_{i,t} = \alpha_i + \alpha_{s,t} + \beta_1 l_{i,t-1}^{ST}\epsilon_t^m + \delta_1 l_{i,t-1}^{ST} + \beta_2 l_{i,t-1}^{LT}\epsilon_t^m + \delta_2 l_{i,t-1}^{LT} + \Gamma' Z_{i,t-1} + \Upsilon\epsilon_t^m Z_{i,t-1} + e_{i,t}$, where $s_{i,t}$ is firm-level daily stock return, α_i is a firm fixed-effect, $\alpha_{s,t}$ is an FOMC day x sector fixed-effect, $l_{i,t-1}^{ST}$ ($l_{i,t-1}^{LT}$) is four-quarter moving average short-term (long-term) leverage normalized to have mean 0 and variance 1, ϵ_t^m are the monetary policy shocks and $Z_{i,t-1}$ is a vector of firm-level controls. ϵ_t^m (FFR) is normalized to have a 25bps effect on mp1, ϵ_t^m (FG) is normalized to have a 25bps effect on the intraday 2 year yield and ϵ_t^m (LSAP) is normalized to have a 25bps effect on the intraday 10 year yield. A positive value of ϵ_t^m represents an expansionary shock. Pre-crisis is from Jul-1991 to Jun 2008, and post-crisis is from Aug 2009 to Dec-2017. The sample is non-financial firms in S&P 500 on the date of the FOMC announcement. Two-way clustered (by firm and FOMC day) standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

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A.4 Alternative Scaling of Monetary Policy Shocks

In Table A.11, we show the results with alternative scalings of the monetary policy shock. In Panel A, ϵ_t^m (FFR) is normalized to have a 25bps effect on mp1, ϵ_t^m (FG) is normalized to have a 25bps effect on the intraday 2 year yield and ϵ_t^m (LSAP) is normalized to have a 25bps effect on the intraday 10 year yield. In Panel B, all shocks have a unit SD. In Panel C, shocks are scaled as in Panel A, except to a 1pp effect. In Panel D, shocks are in the original Swanson (2021) scaling.

Table A.11: Response of firm-level stock returns to monetary shocks with alternate scalings

Panel A: 25bps effect	(1a) Pre-Crisis	(1b) Post-Crisis	(1c) Non-ZLB Post-Crisis
FFR x Leverage	-0.63**		0.02
	(0.249)		(0.537)
FG x Leverage	0.55*	0.08	
	(0.307)	(0.092)	
LSAP x Leverage		0.42***	
		(0.156)	
Observations	37,961	21,907	7,234
R^2	0.220	0.398	0.319

Panel B: Unit SD	(1a) Pre-Crisis	(1b) Post-Crisis	(1c) Non-ZLB Post-Crisis
FFR x Leverage	-0.18**		0.00
	(0.070)		(0.152)
FG x Leverage	0.10*	0.01	
	(0.054)	(0.016)	
LSAP x Leverage		0.04***	
		(0.014)	
Observations	37,961	21,907	7,234
R^2	0.220	0.398	0.319

Panel C: 1 p.p. effect	(1a) Pre-Crisis	(1b) Post-Crisis	(1c) Non-ZLB Post-Crisis
FFR x Leverage	-2.52**		0.07
	(0.995)		(2.149)
FG x Leverage	2.19*	0.33	
	(1.228)	(0.367)	
LSAP x Leverage		1.69***	
		(0.622)	
Observations	37,961	21,907	7,234
R^2	0.220	0.398	0.319

Panel D: Swanson (2021)	(1a) Pre-Crisis	(1b) Post-Crisis	(1c) Non-ZLB Post-Crisis
FFR x Leverage	-0.22**		0.01
	(0.087)		(0.187)
FG x Leverage	0.10*	0.01	
	(0.055)	(0.016)	
LSAP x Leverage		0.08***	
		(0.029)	
Observations	37,961	21,907	7,234
R^2	0.220	0.398	0.319

Notes: This table shows results from estimating $s_{i,t} = \alpha_i + \alpha_{s,t} + \beta l_{i,t-1}\epsilon_t^m + \delta l_{i,t-1} + \Gamma' Z_{i,t-1} + \Upsilon \epsilon_t^m Z_{i,t-1} + e_{i,t}$, where $s_{i,t}$ is firm-level daily stock return, α_i is a firm fixed-effect, $\alpha_{s,t}$ is an FOMC day x sector fixed-effect, $l_{i,t-1}$ is four-quarter moving average leverage normalized to have mean 0 and variance 1, ϵ_t^m are the monetary policy shocks and $Z_{i,t-1}$ is a vector of firm-level controls. In Panel A, ϵ_t^m (FFR) is normalized to have a 25bps effect on mp1, ϵ_t^m (FG) is normalized to have a 25bps effect on the intraday 2-year yield, and ϵ_t^m (LSAP) is normalized to have a 25bps effect on the intraday 10-year yield. In Panel B, all shocks have a unit SD. In Panel C, shocks are scaled as in Panel A, except for a 1pp effect. In Panel D, shocks are in the original Swanson (2021) scaling. A positive value of ϵ_t^m represents an expansionary shock. Pre-crisis is Jul-1991 to Jun-2008, post-crisis is Aug-2009 to Jun-2019, and non-ZLB is Jan-2016 to Jun-2019. The sample is non-financial firms in S&P 500 on the date of the FOMC announcement. Two-way clustered (by firm and FOMC day) standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

B Theoretical Appendix

B.1 Derivation of the Slope of Optimal New Debt Issuance Policy

Derive $\mathbf{b'^*}$ and $\mathbf{\Gamma}$ The optimal new debt position:

$$b'^* = \frac{m(b'^*)}{S}\Big(\frac{[1 - S\Phi\,(b'^*)]}{[1 - \Phi\,(b'^*)]} - \frac{R_1 k_1}{\gamma}\Big) + b \tag{12}$$

where $k_1 \equiv 1 + \frac{[1-S\Phi(b'^*)](b'^*-b)}{R_1 R_2}$ is the capital stock at the first period and $m(b'^*) = [1 - \Phi\,(b'^*)]\,/\phi(b'^*)$ is the Mills ratio of normal distribution that $m(b') > 0$, $m'(b') < 0$, and $m'(b' \to \infty) \to 0$. With the assumption that γ is sufficiently large, i.e., $\gamma > R_1 k_1$ for any feasible R_1 and k_1, $b'^* - b > 0$ always holds, which makes all firms with any levels of initial debt b financially constrained.

Directly solving the expression of $\partial b'^*/\partial b$ and proving it is bounded is not feasible. Starting with the first order condition $\widetilde{v}_{b'} \equiv \partial\widetilde{v}(b)/\partial b' = 0$ as follows:

$$\underbrace{\frac{\gamma}{R_1 k_1}\Big(\,\big[1 - S\Phi\,\big(b'^*\big)\big] - S\phi(b'^*)(b'^* - b)\Big)}_{\text{marginal refinance gain}} - \underbrace{[1 - \Phi(b'^*)]}_{\text{marginal default loss}} = 0 \tag{13}$$

By the theorem of implicit function, $\partial b'^*/\partial b$ could be written as:

$$\frac{\partial b'^*}{\partial b} \equiv -\frac{\widetilde{v}_{bb'}}{\widetilde{v}_{b'b'}} \tag{14}$$

We could first derive the cross-partial derivative $\widetilde{v}_{bb'}$ to be positive:

$$\widetilde{v}_{bb'} \equiv \frac{\partial}{\partial b'}\left(\frac{\partial\widetilde{v}(b)}{\partial b}\right) = \frac{\gamma\left(R_1 S\phi(b'^*) + \frac{[1-S\Phi(b'^*)]^2}{R_2}\right)}{\left(R_1 k_1\right)^2} > 0 \tag{15}$$

We could then derive $\widetilde{v}_{b'b'}$. Since the optimal choice b' maximize $\widetilde{v}$, $\widetilde{v}_{b'b'} < 0$ holds, specifically,

$$\widetilde{v}_{b'b'} \equiv \frac{\partial}{\partial b'}\left(\frac{\partial\widetilde{v}(b)}{\partial b'}\right) = -\frac{\gamma S\,\phi(b')\Big(2 - b'(b' - b)\Big)}{R_1 k_1} - \frac{[1 - \Phi(b')]^2}{\gamma R_2} + \phi(b') < 0 \tag{16}$$

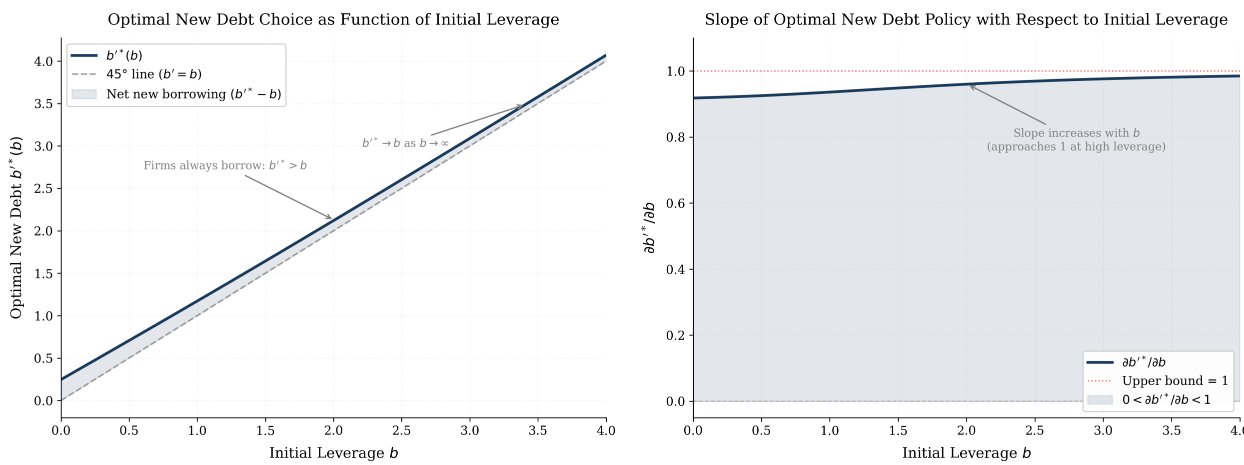
Then, $\partial b'^*/\partial b$ and Γ could be written as:

$$\frac{\partial b'^*}{\partial b} \equiv -\frac{\widetilde{v}_{bb'}}{\widetilde{v}_{b'b'}} = \frac{\frac{\gamma\left(R_1 S\phi(b'^*)+\frac{[1-S\Phi(b'^*)]^2}{R_2}\right)}{\left(R_1 k_1\right)^2}}{\frac{\gamma S\,\phi(b'^*)\left(2-b'^*(b'^*-b)\right)}{R_1 k_1} + \frac{[1-\Phi(b'^*)]^2}{\gamma R_2} - \phi(b')} > 0 \tag{17}$$

$$\Gamma \equiv R_1 k_1 \frac{\partial b'^*}{\partial b} = \frac{\gamma\left(R_1 S\phi(b'^*) + \frac{[1-S\Phi(b'^*)]^2}{R_2}\right)}{\gamma S\,\phi(b'^*)\Big(2 - b'^*(b'^* - b)\Big) + R_1 k_1\frac{[1-\Phi(b'^*)]^2}{\gamma R_2} - R_1 k_1\phi(b'^*)} \tag{18}$$

Simulation of b'^* and $\partial b'^*/\partial b$ at Normal Times Although we can not provide proof of the bounded properties of b'^* and $\partial b'^*/\partial b$, we could provide a simple simulation illustration of the stylized three-period model. Figure A.2 plots such illustrations. First, as initial leverage b increases, it is harder for the firm to issue new debt at low prices q, so $b'^* \to b$ as b increases. In the limit, $b'^* = b$. Consequently, $\partial b'^*/\partial b \to 1$ as initial leverage b increases. Second, even when the initial leverage b is low, $\partial b'^*/\partial b$ is still substantially large. We cannot provide proof, but we can illustrate it in Figure A.2 below. Overall, $0 < \Gamma \equiv R_1 k_1 \frac{\partial b'^*}{\partial b} < R_1 k_1 < \gamma$ and $\partial b'^*/\partial b$ is substantially large compare to 0.

Figure A.2: An Example for b'^* and $\partial b'^*/\partial b$ at Normal Times

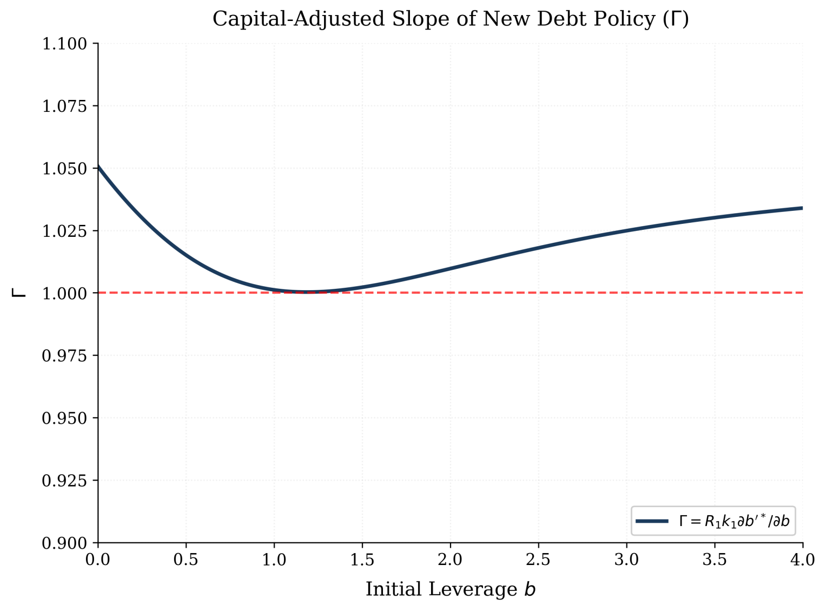


Notes: This plot shows that the value of b'^* with $\gamma = 1.5$, $R_1 = R_2 = 1.05$, and $S = 1$. As initial debt $b \to \infty$, $b'^* \to b$ and $\partial b'^*/\partial b \to 1$ as initial leverage b increases.

Simulation of Γ Function At normal times, we could choose $\gamma = 1.5$, $R_1 = R_2 = 1.05$, and $S = 1$. The capital-adjusted slope of the optimal new debt position as a policy function of initial leverage Γ is bounded as shown in Figure A.3. Changing $\{\gamma, R_1, R_2\}$ within reasonable and feasible ranges only affects the shape and the level of the lower bound, but not the bounded properties. For instance, keeping $\gamma > R_1 k_1$ for largest feasible k_1 holds, change $\{R_1 \in [0.8, 1.2], R_2 \in [0.8, 1.2], S \in [0.8, 1.2]\}$ would preserve the shape of $\partial b'^*/\partial b$ in Figure A.3 below.

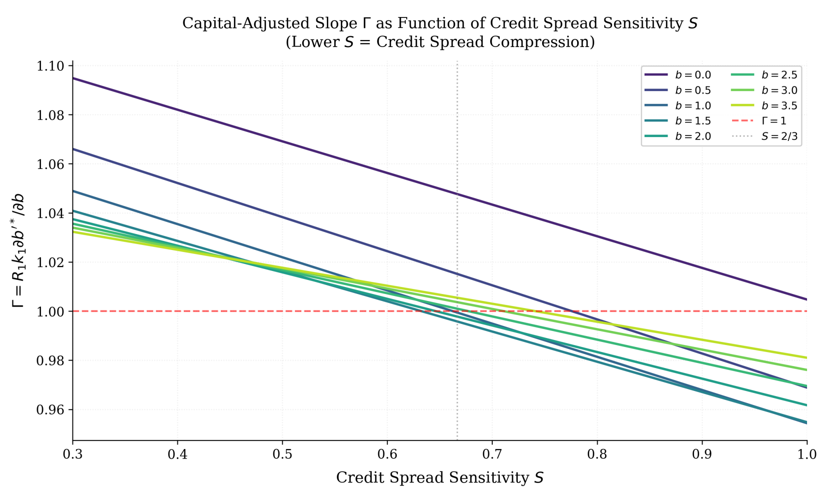
Simulation of $\partial\Gamma/\partial S$ Under credit spread compression, we could again choose $\gamma = 1.5$, $R_1 = R_2 = 1.05$, but let S vary. The capital-adjusted slope of the optimal new debt position as a policy function of initial leverage Γ is bounded as shown in Figure A.4 below. It is obvious that with credit spread compression, which decreases S, Γ increases with different initial leverage b.

Figure A.3: An Example for the Value of Γ at Normal Times



Notes: This plot shows that the value of Γ with $\gamma = 1.5$, $R_1 = R_2 = 1.05$, and $S = 1$. As initial debt $b \to \infty$, $\Gamma \to R_1 k_1$.

Figure A.4: An Example for the Value of Γ with Credit Spread Compression



Notes: This plot shows that the value of Γ with $\gamma = 1.5$, $R_1 = R_2 = 1.05$, and initial leverage at different levels under credit spread compression. As credit spread compression increases ($S \to 0$), Γ increases to be above unity.

B.2 Derivation of the Effects of Conventional Monetary Shocks

In this section, we derive the effects of conventional monetary shocks.

First, we derive $\frac{\partial}{\partial(-R_1)}\left(\frac{\partial\widetilde{v}(b)}{\partial b}\right)\Big|_{\text{fix } b'^*}$ with fixed b'^* from $\tilde{v}_b$ in equation (8) and take $S=1$:

$$\begin{aligned}
\tilde{v}_{bm_1}|_{\text{fix } b'^*} &\equiv \frac{\partial}{\partial(-R_1)}\left(\frac{\partial\widetilde{v}(b)}{\partial b}\right)\Big|_{\text{fix } b'^*} = (-1)\cdot\frac{\partial}{\partial(R_1)}\left(\frac{\partial\widetilde{v}(b)}{\partial b}\right)\Big|_{\text{fix } b'^*} \\
&= (-1)\cdot\frac{\partial}{\partial R_1}\left(-\frac{\gamma\left[1-\Phi\left(b'^*\right)\right]}{R_1+\frac{[1-\Phi(b'^*)](b'^*-b)}{R_2}}\right) \\
&= \gamma\left[1-\Phi\left(b'^*\right)\right]\cdot-\left(\frac{1}{R_1+\frac{[1-\Phi(b'^*)](b'^*-b)}{R_2}}\right)^2 \\
&= -\frac{\gamma[1-\Phi(b'^*)]}{(R_1k_1)^2}
\end{aligned} \tag{19}$$

Second, we derive $\frac{\partial}{\partial(-R_1)}\left(\frac{\partial\widetilde{v}(b)}{\partial b'}\right)$ from $\tilde{v}_{b'}$ in the left-hand side of equation (6), take $S=1$, and also consider that equation (6) holds, so that $\frac{\gamma}{R_1k_1}\Big(\left[1-S\Phi\left(b'^*\right)\right]-S\phi(b'^*)(b'^*-b)\Big)=[1-\Phi(b'^*)]$:

$$\begin{aligned}
\tilde{v}_{b'm_1} &\equiv \frac{\partial}{\partial(-R_1)}\left(\frac{\partial\widetilde{v}(b)}{\partial b'}\right) = (-1)\cdot\frac{\partial}{\partial(R_1)}\left(\frac{\partial\widetilde{v}(b)}{\partial b'}\right) \\
&= (-1)\cdot\frac{\partial}{\partial R_1}\left(\frac{\gamma\Big(\left[1-S\Phi\left(b'^*\right)\right]-S\phi(b'^*)(b'^*-b)\Big)}{R_1+\frac{[1-\Phi(b'^*)](b'^*-b)}{R_2}}-\left[1-\Phi(b'^*)\right]\right) \\
&= \gamma\Big(\left[1-S\Phi\left(b'^*\right)\right]-S\phi(b'^*)(b'^*-b)\Big)\left(\frac{1}{R_1+\frac{[1-\Phi(b'^*)](b'^*-b)}{R_2}}\right)^2 \\
&= \gamma\Big(\left[1-S\Phi\left(b'^*\right)\right]-S\phi(b'^*)(b'^*-b)\Big)\left(\frac{1}{R_1k_1}\right)^2 \\
&= \frac{[1-\Phi(b'^*)]}{R_1k_1}
\end{aligned} \tag{20}$$

The ratio $-\tilde{v}_{b'm_1}/\left.\tilde{v}_{bm_1}\right|_{\text{fix } b'^*}=R_1k_1/\gamma<1$ measures the relative importance of the refinance channel to the financial overhang channel of monetary policy, which is smaller than unity. Finally, the cross partial derivative $\widetilde{v}_{bm_1}$ can be expressed as

$$\begin{aligned}
\widetilde{v}_{bm_1} &= \frac{\partial}{\partial(-R_1)}\left(\frac{\partial\widetilde{v}(b)}{\partial b}\right)\Big|_{\text{fix } b'^*}+\frac{\partial}{\partial(-R_1)}\left(\frac{\partial\widetilde{v}(b)}{\partial b'}\right)\cdot\frac{\partial b'^*}{\partial b} \\
&= -\frac{\gamma[1-\Phi(b'^*)]}{(R_1k_1)^2}+\frac{[1-\Phi(b'^*)]}{R_1k_1}\cdot\frac{1}{R_1k_1}\Gamma \\
&= \underbrace{\frac{\gamma[1-\Phi(b'^*)]}{(R_1k_1)^2}}_{\text{shock multiplier}}\cdot\Big(\underbrace{-1}_{\text{financial overhang}}+\underbrace{\Gamma/\gamma}_{\text{refinancing benefit}}\Big)<0
\end{aligned} \tag{21}$$

B.3 Derivation of the Effects of Unconventional Monetary Shocks

In this section, we derive the effects of unconventional monetary shocks.

First, we derive $\frac{\partial}{\partial(-S)}\left(\frac{\partial\widetilde{v}(b)}{\partial b}\right)\Big|_{\text{fix } b'^*}$ with fixed b'^* from $\tilde{v}_b$ in equation (8):

$$\begin{aligned}
\tilde{v}_{bm_2}|_{\text{fix } b'^*} &\equiv \frac{\partial}{\partial(-S)}\left(\frac{\partial\widetilde{v}(b)}{\partial b}\right)\Bigg|_{\text{fix } b'^*} = (-1)\cdot\frac{\partial}{\partial(S)}\left(\frac{\partial\widetilde{v}(b)}{\partial b}\right)\Bigg|_{\text{fix } b'^*} \\
&= (-1)\cdot\frac{\partial}{\partial S}\left(-\frac{\gamma\left[1-S\Phi\left(b'^*\right)\right]}{R_1+\frac{[1-S\Phi(b'^*)](b'^*-b)}{R_2}}\right) \\
&= \frac{-\gamma\Phi\left(b'^*\right)}{R_1+\frac{[1-S\Phi(b'^*)](b'^*-b)}{R_2}} + \frac{\gamma\Phi(b'^*)\frac{[1-S\Phi(b'^*)](b'^*-b)}{R_2}}{\left(R_1+\frac{[1-S\Phi(b'^*)](b'^*-b)}{R_2}\right)^2} \\
&= -\frac{\gamma\Phi\left(b'^*\right)\left(R_1+\frac{[1-S\Phi(b'^*)](b'^*-b)}{R_2}\right)-\gamma\Phi(b'^*)\frac{[1-S\Phi(b'^*)](b'^*-b)}{R_2}}{\left(R_1k_1\right)^2} \\
&= -\frac{\gamma R_1\Phi(b'^*)}{\left(R_1k_1\right)^2}
\end{aligned} \tag{22}$$

Second, we derive $\frac{\partial}{\partial(-S)}\left(\frac{\partial\widetilde{v}(b)}{\partial b'}\right)$ from $\tilde{v}_{b'}$ in the left-hand side of equation (6), and also consider that equation (6) holds, so that $\frac{\gamma}{R_1k_1}\Big([1-S\Phi\left(b'^*\right)]-S\phi(b'^*)(b'^*-b)\Big)=[1-\Phi(b'^*)]$:

$$\begin{aligned}
\tilde{v}_{b'm_2} &\equiv \frac{\partial}{\partial(-S)}\left(\frac{\partial\widetilde{v}(b)}{\partial b'}\right) = (-1)\cdot\frac{\partial}{\partial(S)}\left(\frac{\partial\widetilde{v}(b)}{\partial b'}\right) \\
&= (-1)\cdot\frac{\partial}{\partial S}\left(\frac{\gamma\Big([1-S\Phi\left(b'^*\right)]-S\phi(b'^*)(b'^*-b)\Big)}{R_1+\frac{[1-S\Phi(b'^*)](b'^*-b)}{R_2}} - [1-\Phi(b'^*)]\right) \\
&= \frac{\gamma\Phi(b'^*)+\gamma\phi(b'^*)(b'^*-b)}{R_1k_1} - \frac{\frac{1}{R_2}\Phi(b'^*)[1-\Phi(b'^*)](b'^*-b)}{R_1k_1} \\
&= \frac{\gamma\Phi(b'^*)}{R_1k_1}\left(1+\left(\frac{\phi(b'^*)}{\Phi(b'^*)}-\frac{[1-\Phi(b'^*)]}{\gamma R_2}\right)(b'^*-b)\right) \\
&\equiv \frac{\gamma\Phi(b'^*)}{R_1k_1}\cdot\Psi \\
&> \frac{\gamma\Phi(b'^*)}{R_1k_1}, \qquad \text{where } \Psi\geq 1
\end{aligned} \tag{23}$$

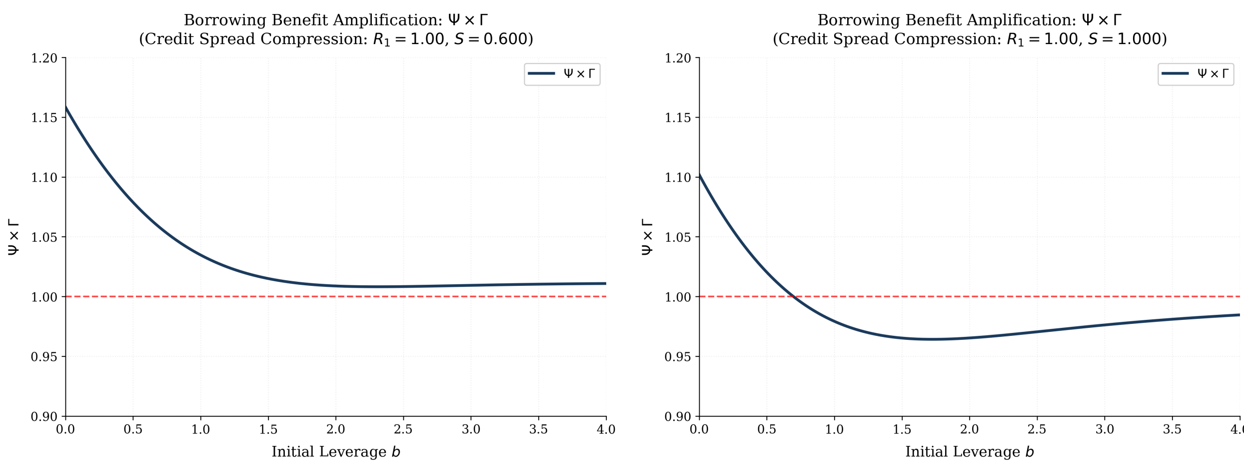
where the multiplier $\left(\frac{\phi(b'^*)}{\Phi(b'^*)}-\frac{[1-\Phi(b'^*)]}{\gamma R_2}\right)$ on net debt issuance in the second term is greater than $(\phi(b'^*)/\Phi(b'^*)-[1-\Phi(b'^*)])$, which is greater or equal to zero from the property of normal distribution. So $\Psi\geq 1$ always hold until $b'^*\to\infty$. So,

$$\Psi \equiv 1+\left(\frac{\phi(b'^*)}{\Phi(b'^*)}-\frac{[1-\Phi(b'^*)]}{\gamma R_2}\right)\cdot(b'^*-b)\geq 1 \tag{24}$$

The ratio $-\tilde{v}_{b'm_2}/\left.\tilde{v}_{bm_2}\right|_{\text{fix } b'^*} > R_1k_1/R_1 > 1$ measures the relative importance of the refinance channel to the financial overhang channel of monetary policy, which is greater than unity. Finally, let $R_1 = 1$ at the zero lower bound, the cross partial derivative $\widetilde{v}_{bm_2}$ can be expressed as

$$\begin{aligned} \widetilde{v}_{bm_2} &= \frac{\partial}{\partial(-S)}\left(\frac{\partial \widetilde{v}(b)}{\partial b}\right)\bigg|_{\text{fix } b'^*} + \frac{\partial}{\partial(-S)}\left(\frac{\partial \widetilde{v}(b)}{\partial b'}\right)\cdot\frac{\partial b'^*}{\partial b} \\ &= -\frac{\gamma\Phi(b'^*)}{k_1^2} + \frac{\gamma\Phi(b'^*)}{k_1}\cdot\Psi\cdot\frac{1}{k_1}\Gamma \\ &= \underbrace{\frac{\gamma\Phi(b'^*)}{k_1^2}}_{\text{shock multiplier}}\cdot\Big(\underbrace{-1}_{\text{financial overhang}} + \underbrace{\Gamma\cdot\Psi}_{\text{borrowing benefit}}\Big) \lesseqgtr 0 \end{aligned} \tag{25}$$

Figure A.5: An Example for $\Gamma \cdot \Psi$ with/without Credit Spread Compression



(a) With Credit Spread Compression

(b) Without Credit Spread Compression

Notes: This plot shows that the value of $\Gamma \cdot \Psi$ in the above equation (12) with $\gamma = 1.5$, $R_2 = 1.05$, $R_1 = 1$ (zero lower bound), and now $S = 2/3$ (with credit spread compression) versus $S = 1$ (without credit spread compression).